Study of the combined effect of sowing date and sowing method on vegetative development of new rice paddy (Oryza sativa) varieties in Senegal River Valley under low temperatures

Koffi Marchais KITTIKA1,2*, Omar Ndaw FAYE2 and Anicet Georges Bruno MANGA1

1UFR Sciences Agronomiques d’Aquaculture et des Technologies Alimentaires, Université Gaston Berger de Saint-Louis, Saint-Louis, Senegal.
2Centre de Recherches Agricoles de Saint-Louis de l’Institut Sénégalais de Recherches Agricoles (CRA/ISRA/SL), Saint-Louis, Senegal.

Rice paddy cultivation in Senegal is subject to climatic fluctuations that affect its vegetative development. Although climatic conditions are a concern, we hypothesized that the new rice paddy ISRIZ would be better adapted to these fluctuations and would allow double cropping. We studied the vegetative behavior according to the date and mode sowing under low temperatures. An experiment was carried out in a split-split plot design with sowings staggered every three weeks (18 dates), and two sowing modes (Broadcast, transplanting). Data collected included plant height, number of tillers, 50% flowering, 80% maturity. The results showed that the sowing date and method had significant effects on the morphology of the varieties. These effects were exacerbated by low temperatures, resulting in a lengthening of the cycle of the varieties. Some varieties performed well with flowering cycles of less than 100 days and are adapted to double cropping. The best planting period during the hot dry season is between February and March, while in winter, planting between July and August is recommended. In the cold, the practice of transplanting is better adapted. This study identified new varieties that could be adapted to the practice of double cropping in a context of climatic variability.

Key words: Irrigated rice, sowing dates, low temperatures, double cropping.

INTRODUCTION

In West Africa, many farmers face unpredictable yields due to various constraints, including climatic hazards. This leads to lower incomes and increased food insecurity in the region. In addition, climate change will pose enormous challenges to food security (Johnson and Brown, 2014; Waongo et al., 2015). One of the crops
facing the challenges of climate change is rice production, which has become a staple food and a strategic commodity for much of the world’s population (Fall, 2007; Matlon et al., 2011). Rice is one of the most important cereal crops, and maintaining high and stable rice production is an important prerequisite for ensuring food security (Guo et al., 2020; Wang et al., 2021; Xu et al., 2016). Rice, being a thermophile plant, finds optimal condition for photosynthesis at temperatures of 25 to 35°C (var. indica) or 20 to 33°C (var. japonica) (Yoshida, 1981). Although it can adapt to a wide range of temperatures, depending on the variety, rice is sensitive to temperature peaks (low and high) at certain stages of its phenology. The growth and development process of rice are susceptible to temperature changes, especially a decrease in temperature (Ohno et al., 2018; Wang et al., 2021). This often requires a precise choice of varieties to be planted according to the growing season. Several studies have shown that the microspore stage is very sensitive to low temperatures, which inhibit microspore development, modify the anther proteome and lead to spikelet sterility (Godwin et al., 1994; Imin et al., 2006; Mamun et al., 2006). In Senegal, rice is grown intensively in the Senegal River Valley. In order to increase yields, double cropping is practised, mainly in irrigated mode. However, in recent years, the success of double cropping has become increasingly difficult due to factors such as climate, technical itineraries and pest pressure (Sie, 1997). Indeed, the main rice paddy season takes place during the hot dry season from mid-February to mid-March. The area planted during the winter season (from the end of July to the end of August) is constantly decreasing due to various constraints, including climatic hazards. As a result, the choice of varieties and sowing date are necessary elements inherent to good rice productivity. In order to cope with the drop in yields, eight new ISRIZ varieties released by the Agricultural Research Centre of Saint-Louis, Senegal and being disseminated in the Senegal River Valley have been developed. However, no studies have been conducted on their vegetative behaviour in relation to possible environmental changes. Thus, the objective of this study was to determine which of the new varieties are likely to have good vegetative behaviour in relation to sowing date and method. This research study could help to better adapt rice paddy production in the Senegal River Valley to climate change.

MATERIALS AND METHODS

Location and climatic conditions of the study site

The experiment was carried out at the Experimental Station of the Centre de Recherches Agricoles of the Senegalese Institute of Agricultural Research in Fanaye, Senegal (16°33N and 15°46W).

The climate of the site is characterised by a rainy season with an average of 200 mm of rainfall per year from July to October, a cold dry season from November to February and a dry season from March to June (Haefele et al., 2004).

Plant

The planting material is composed of twelve (12) varieties of various origins (Table 1). Four released varieties (Nerica S.44; Sahel 108; Sahel 177 and Sahel 201), which account for more than 95% of the area planted in valley, were chosen as controls because of their good adaptation to the climatic conditions of the Senegal River Valley (SRV).

Experimental design

A split-split plot design was used. The factors studied were the variety (twelve), the sowing method (with two modalities: direct broadcast sowing and sowing in a nursery followed by transplanting), and the sowing date (with thirteen modalities: sowing every 21 days). Table 2 summaries the different sowing dates.

Crop management

Soil preparation

The soil was worked after pre-irrigation by means of double pass offset discs, about 10-15 cm (uniform) deep, and mechanical levelling. This was essential for water management, weed control and good distribution of fertilisers.

Pre-sprouting: Pre-germination was done in two (soaking and incubation) to trigger the germination process (Table 2). Soaking consisted of soaking the seed in a cloth bag with water for 24 h in a container. This allowed the seeds to absorb the necessary amount of water to trigger germination. Incubation consisted of placing the seed bags after 24 h of soaking in a well-ventilated place at a temperature of about 30°C for 24 h until germination. At the end of this time, the seeds germinated well. From November onwards, when the cold weather started to set in, the incubation period was extended from 24 to 48 h.

Sowing method: In direct sowing, the quantity of seed used was 80 kg/ha, that is, 40 g of seed per 5 m² (5 m × 1 m) elementary plot. In nursery sowing, the quantity of seed used is 40 kg/ha, that 20 g of seed sown in trays. Transplanting was done twenty-one days in the nursery on 5 m² (5 m × 1 m) elementary plots with spacing of 20 cm by 20 cm.

Fertilisation of experimental plots: NPK nutrient requirements, estimated at 120-60-60 per unit were applied, DAP (18-46-00) as a basal fertiliser and urea (46-00-00) as a cover fertiliser. Urea was applied in two fractions, 50% at the beginning of tillering and 50% at panicle initiation and potassium K (60 kg/ha) in the form of KCl.

Water management in the plots: Rice needs an appropriate amount of water for the different phases of the plant’s development. For both sowing methods, the plots were sown and transplanted respectively under a 5 cm water depth. This water depth was maintained for one week. The plots were then drained and left dry for three days before being irrigated again at a 5 cm water level.
Table 1. Characteristics of the rice paddy varieties tested.

| Variety     | Cycle to maturity (days) | Yield (kg.ha⁻¹) | Others traits                      |
|-------------|--------------------------|-----------------|------------------------------------|
|             | CSC | HIV | Potentials | Field  |                        |
| Isriz 01    | 100 | 88  | 12500      | 8500   | Cold and salt tolerance |
| Isriz 02    | 110 | 90  | 1200       | 8500   | Cold tolerance          |
| Isriz 03    | 120 | 92  | 13500      | 8600   | Cold and salt tolerance |
| Isriz 04    | 125 | 105 | 13500      | 8500   | Cold tolerance          |
| Isriz 05    | 125 | 104 | 13500      | 87200  | Cold tolerance          |
| Isriz 06    | 120 | 103 | 13500      | 7224   | Cold tolerance          |
| Isriz 07    | 123 | 106 | 12500      | 7500   | Cold tolerance          |
| Isriz 12    | 127 | 106 | 12000      | 8000   | Cold, water deficit tolerance |
| Nerica_S_44 | 122 | 110 | 12000      | 8000   | Short cycle             |
| Sahel 108   | 117 | 105 | 10000      | 7000   | Short cycle, grown in the CSC |
| Sahel 177   | 122 | 112 | 10000      | 7000   | Aromatic, grown in CSC  |
| Sahel 201   | 142 | 121 | 10000      | 6000   | Medium cycle            |

CSC: Counter hot season; HIV: winter season.
Source: Faye and Fall (2018)

Table 2. The different sowing dates from D1 to D18.

| Date    | Tramping  | Incubation | Broadcast | Transplanting |
|---------|-----------|------------|-----------|---------------|
| D1      | 02/01/2017| 03/01/2017| 05/01/2017| 26/01/2017    |
| D2      | 23/01/2017| 24/01/2017| 26/01/2017| 16/02/2017    |
| D3      | 13/02/2017| 14/02/2017| 16/02/2017| 09/03/2017    |
| D4      | 06/03/2017| 07/03/2017| 09/03/2017| 30/03/2017    |
| D5      | 27/03/2017| 28/03/2017| 30/03/2017| 20/04/2017    |
| D6*     | 18/04/2017| 19/04/2017| 20/04/2017| 11/05/2017    |
| D7*     | 09/05/2017| 10/05/2017| 11/05/2017| 01/06/2017    |
| D8*     | 30/05/2017| 31/05/2017| 01/06/2017| 22/06/2017    |
| D9*     | 20/06/2017| 21/06/2017| 22/06/2017| 13/07/2017    |
| D10*    | 11/07/2017| 12/07/2017| 13/07/2017| 03/08/2017    |
| D11     | 01/08/2017| 02/08/2017| 03/08/2017| 24/08/2017    |
| D12     | 22/08/2017| 23/08/2017| 24/08/2017| 14/09/2017    |
| D13     | 12/09/2017| 13/09/2017| 14/09/2017| 05/10/2017    |
| D14     | 03/11/2017| 04/10/2017| 05/10/2017| 26/10/2017    |
| D15     | 24/10/2017| 25/10/2017| 26/10/2017| 16/11/2017    |
| D16     | 13/11/2017| 14/11/2017| 16/11/2017| 07/12/2017    |
| D17     | 04/12/2017| 05/12/2017| 07/12/2017| 28/12/2017    |
| D18     | 25/12/2017| 26/12/2017| 28/12/2017| 18/01/2018    |

*Data for sowing dates D6 to D10 were not analysed due to unavailability of data for these sowing dates.
Source: Authors

until the third week after direct sowing and transplanting. Again the plots were drained and left dry for two days to apply the herbicide (Propanyl and Weedon (2-4-D)). A new irrigation was carried out and kept at 3 cm for five days for the application of the first fertilizer. The irrigation water was raised to 5 cm until panicle initiation (IP), which marks the beginning of the reproductive phase. For the second fertilizer application, the water level was lowered to 3 cm for five days and then raised to 10-15 cm water level until the doughy grain stage. Finally, from the beginning of repining, the plots were drained until they were completely dry at maturity.
Measured parameters

The temperature data were collected at the Fanaye weather station during the whole experimentation period. The agro-morphological parameters monitored were:

1. The average height of the plants (HAUT).

\[
HAUT = \frac{\text{sum of the heights of 5 plants}}{5}
\]

2. Average number of tillers per plant (TALL):
   a) In transplanting mode.

\[
TALL = \frac{\text{sum of the tillers on 5 poquets}}{\text{area of the 5 poquets}}
\]

b) In direct seeding mode, we counted the number of tillers per meter square

3. Days of 50% flowering (50% FLO): The date at which 50% of the plants in the elementary plot have reached was noted.

\[
50\% \text{ FLO} = \text{Difference between sowing date and 50\% flowering date}
\]

4. Days of 80% maturity (80% MAT): The date at which 80% of the plants in the elementary plot have reached maturity was noted.

\[
80\% \text{ MAT} = \text{Difference between sowing date and 80\% maturity date}
\]

Effect of factors and their interactions on parameters

The analysis of variance of the observed parameters according to sowing date, sowing method and variety as well as the interactions is shown in Table 3. The analysis showed a highly significant effect of sowing date and variety on height, number of tillers, 50% flowering date and 80% maturity date. The sowing method, with the exception of height, also has a highly significant effect on the observed parameters. Indeed, the different interactions between factors on the parameters have been shown and analysed. It is about: Interaction of date × sowing method × variety (D × MS × V); interaction of date × variety (D × V); interaction of sowing mode × variety (V × MS).

Interaction of date × sowing method × variety (D × MS × V) on the parameters

The analysis of variance revealed a highly significant interaction (p<0.001) between the different factors studied (date × sowing method × variety) and a highly significant effect (p<0.001) for all parameters studied (height, number of tillers, 50% flowering and 80% maturity).

Results and discussion

Temperature development during the test period

Minimum temperatures ranged from 12.39 to 22.86°C from January 2017 to April 2018 (Figure 1). The lowest temperatures were recorded in December-January 2017. The same trend was observed in 2018. From February onwards, a gradual increase in temperature was noted, with a peak between June and August 2017 (24 and 26°C), before decreasing to 12.39°C in January 2018. The maximum temperature varied between 28.75 and 38.79°C with peaks between June and October (36 and 38.79°C). Finally, the average temperature varied between 20.41 and 30.12°C. According to these temperature trends, the best sowing period for the off-dry season is from 5 February to 5 March and the rainy season from 5 July to 10 August.
Figure 1. Evolution of the temperature at the test site between January 2017 and April 2018. 
Source: Authors

Table 3. Source of variation, degree of freedom and the mean square of the analysis of variance and the interaction between the different factors on the rice paddy parameters studied.

| Source of variation | Date (D) | Sowing method (MS) | Varieties (V) | V×D | V×MS | D×MS | V×D×MS |
|---------------------|----------|--------------------|---------------|-----|------|------|--------|
|                     | d.f      |                    |               |     |      |      |        |
| HAUT                | 12       | 1                  | 11            | 132 | 11   | 12   | 127    |
| TALL                | 2.2e-16***| 0.268630           | 2.2e-16***    | 2.2e-16*** | 0.080839 | 3.584e-12*** | 0.003856*** |
| 50% FLO             | 2.2e-16***| 2.2e-16***         | 2.2e-16***    | 8.805e-14*** | 1.796e-15*** | 2.2e-16***      | 2.2e-16*** |
| 80%MAT              | 2.2e-16***| 2.2e-16***         | 2.2e-16***    | 2.2e-16***  | 3.935e-9*** | 2.2e-16***      | 2.2e-16*** |

HAUT: Height; TALL: Number of tillers; 50%FLO: days of 50% flowering; 80%MAT: days of 80% maturity. 
Source: Authors

12°C. These results are in agreement with Abdul Aziz et al. (2006) and Akram et al. (2007), who showed that rice height was significantly affected by sowing dates. The good behaviour of varieties sown between January and June could be explained by the weak effect of minimum temperature on the mi-flowering phase of the varieties, and corroborates the results of Goita et al. (2017). Sowing between February and March in the hot dry season and sowing between July and August in the rainy season give better heights than late sowing.

This is line with the work of Bashir et al. (2010), Gravois and Helms (1998) and Saikia et al. (1989), who showed that early sowing of rice gives good heights. This decrease in the height of the rice varieties would be related to the temperatures of each sowing period. On the other hand, the analysis of variance showed a non-significant difference in relation to the sowing mode. This means that the broadcasting or transplanting method had no effect on the height of rice regardless of the sowing date (Figure 2c).

Number of tillers

The analysis of variance, showed a highly significant interaction of date × sowing method × variety on number of tillers. Thus the highest number of tillers per meter square was obtained at D2 (sowing on 26 January) and the lowest number of tillers per meter square was obtained at D18 (sowing in December) (Figure 3a). The maximum number of tillers was produced by the control variety Sahel 108 188.70 tillers/m² and the minimum was produced by the new variety ISRIZ 03 with 79.60 tillers/m² (Figure 3b). As for the sowing method, the number of tillers produced by direct seeding is higher than the number of tillers produced by transplanting (Figure 3c). The difference in the number of tillers according the sowing method is linked to sowing rate.
**Figure 2.** Effect of sowing date; sowing method and variety on height. The bars represent the averages and standard deviations of two repetitions. The different lower case letters indicate statistically significant differences between treatments (P < 0.05; ANOVA, Tukey test).
Source: Authors

**Figure 3.** Effect of sowing date; sowing method and variety on number of tillers. The bars represent the averages and standard deviations of two repetitions. The different lower case letters indicate statistically significant differences between treatments (P < 0.05; ANOVA, Tukey test).
Source: Authors
Indeed, the quantity of seed used in direct seeding mode is reducing by half in transplanting mode. This results in a higher density of plants in direct seeding mode. However, the sowing date is the main factor influencing tillering. Sowing between February and June, when the temperature is between 20 and 30°C, favours good tillers development, contrary to sowing between October and January when the temperature drops to 12°C, which limits tillers development; this confirms the work of Bashir et al. (2010), who showed that the temperature impacts tillers development. Indeed, the varieties ISRIZ 01, ISRIZ 02, ISRIZ 03 and ISRIZ 04 produced less than 100 tillers per meter square, that is, 95.9, 88.9, 79.6 and 95.3, respectively, while the varieties NERICA_S.44; Sahel produced more tillers per meter square.

**Days of 50% flowering**

The analysis of variance of date × sowing method × variety on 50% flowering showed a highly significant interaction (p<0.001) at the 5% threshold. The days of 50% flowering varied from 85.2 to 115.4. According to the sowing date, the maximum day taken to reach 50% flowering was 130.45 observed at date D18 (sown in December) while the minimum day was 67.10, observed at date D4 (sown in March) (Figure 4a). The control variety Sahel 201 took 115.4 days (highest number of days) to reach this stage, while the new variety ISRIZ 03 took 85.2 days which is the minimum number of days. This difference in days to reach 50% flowering confirms that the varieties tested are different from each other and have different cycles (Figure 4b). For the January sowings (D1), when the temperature is between 15 and 20°C, the varieties reached 50% flowering after more than 90 days (Figure 4b). This trend was more remarkable for the D17 and D18 sowings (sown on December 7 and 28th respectively) where temperature were below 15°C. These low temperatures resulted in 50% lengthening of the varieties. Temperature affects two critical processes in rice production in the sahel: the length of the growth cycle and the sterility of the spikelet, induced by heat or cold stress (Dingkuhn and Miezan, 1995). From date D3 to D12, the days of 50% flowering
of the varieties did not increase compared to the normal length of the growth cycle. Between these sowing dates (March-September), minimum temperatures are between 20 and 26°C and are optimal for good rice development. According to Wopereis et al. (2008), cold temperatures during the vegetative phase slow down the development of rice and thus lengthen the cycle. Low temperature in the vegetative stage can cause slow growth and reduced seedling vigour (Ali et al., 2006), low seedling numbers, reduced tillering (Shimono et al., 2002), and increased plant mortality (Baruah et al., 2009; Farrell et al., 2006; Fujino et al., 2004) increase the growth period (Alvarado and Hernaiz, 2007) and at the reproductive stage, it can cause panicle sterility and a decrease in production and yield (Shimono et al., 2002). Depending on the sowing method, the days of 50% flowering stage was reached more often with broadcast than transplanting (Figure 4c). This difference in days between direct seeding and transplanting is thought to be due to transplanting shock experienced by the transplanted rice paddy seedlings.

**Days of 80% maturity**

The analysis of variance of date × sowing method × variety on 80% maturity showed a highly significant interaction. The control variety Sahel 201 has the longest cycle (147.4 days) and ISRIZ 03 is the variety with the shortest cycle, while the highest number of days (162.6) was obtained at date D18 (sowing in December) and the shortest (89.5) was obtained at date D4 (sowing in March) (Figure 5a and b). Sabouri et al. (2008) showed the effect of different sowing dates on the maturity of different rice genotypes. In cold regions with short seasons, rice takes a long time to mature or even longer to become sterile. As with the days of 50% flowering, the direct seeded varieties reached 80% maturity earlier than the transplanting would be due to the transplanting shock. Indeed, transplanting implies a change of environment for the young seedlings and they are cut off from their hydro-mineral network. Thus, the young seedlings have to re-establish their root system in their new environment to connect to the hydro-mineral network, while direct seeded rice develops rapidly (Huang et al., 2011; Wu et al., 2019). In addition no till rice also regulates its physiological processes by changing the concentration of endogenous hormones in the plant body during low temperature stress (Wang et al., 2021).

**Effect of interaction date × variety on parameters and ANOVA probability**

Table 3 shows the analysis of date × variety on the parameters studied. Indeed, the analysis showed a highly
significant interaction for all parameters (height, number of tillers, days of 50% flowering and days of 80% maturity). The combination of sowing date and variety (Figure 6) had effect on parameters such as height, number of tillers, days of 50% flowering, and days of 80% maturity. Low temperatures and low humidity related to sowing date strongly affect rice growth (Kuwagata et al., 2012). This effect is even more significant for sowing periods when temperatures were below 20°C. Sowing date and variety have a significant impact on height and number of tillers (Praveen et al., 2018). Early sowing allows the plants to benefit from better environmental conditions, especially temperature and solar radiation (Shehzad et al., 2012). Wang et al. (2021) demonstrated the effect of low temperature and variety on rice height.

**Effect of sowing mode × variety on parameters and ANOVA probability**

Analysis of the interaction between sowing mode and variety showed that the interaction was highly significant on the number of tillers, the date of 50% and the date of 80% maturity (Table 3). On the other hand, the MS × V combination had no effect on height (p<0.08). Therefore, the sowing method did not influence height regardless of the sowing date. However, with the increase in global temperature and the appearance of periods of extremes, rice in direct sowing often suffers from low temperatures at the sowing stage compared to transplanted rice (Peng et al., 2007; Wang et al., 2021). In contrast, Lawali et al. (2018) demonstrated in their study that early and late

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**Figure 6.** Effect of interaction date × variety on height (a), number of tillers (b); days of 50% flowering (c) and days of 80% maturity (d).

Source: Authors

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transplanting of seedlings has an impact on flowering and maturity date in millet. They show in the same study the number of tillers is significant for both early and late transplanting (Lawali et al., 2018). Direct seeding is practiced more than transplanting because of cost reduction and operational simplicity (Wang et al., 2021). Therefore, the sowing method did not influence height regardless of the sowing date (Figure 7).

**Principal component analysis (PCA) and hierarchical ascending classification (HAC)**

**Principal component analysis**

The principal component analysis carried out on the variables studied showed the correlations between height (HAUT), number of tillers (TALL), days of 50% flowering and days of 80% maturity. Axes 1 and 2 represent 91.52% of the variable information. Thus, height is negatively correlated with the number of tillers but it is positively correlated with the cycle (days of 50% flowering and days of 80% maturity). These results are in agreement with the results of Do et al. (2020). These authors conducted studies on the agro-morphological characterisation of fonio and demonstrated the negative correlation between height, number of tillers and cycle. The number of tillers is positively correlated with the cycle and there is a strong correlation between the days of 50% flowering and the days of 80% maturity. These results corroborate those of BA (2020), who also showed in his studies that the days of 50% flowering is positively correlated with the days of 80% maturity. The principal component analysis carried out on the variables studied showed the correlations between height (HAUT), number of tillers (TALL), days of 50% flowering and days of 80% maturity (Figure 8).

**Hierarchical ascending classification**

Figure 9 shows the classification of the varieties according to the parameters studied. Three groups of varieties were determined (Figure 9).
Indeed, three groups of varieties can be distinguished according to the production cycle and the production period. Group 1 consists of the short-cycle varieties ISRIZ 01, ISRIZ 02 and ISRIZ 03, which are more tolerant of low temperatures and are suitable for double-cropping rice in the Senegal River Valley (SRV). The
second group is made up of SAHEL108 and NERICA-S-44, which are considered to have a short cycle, but are slightly longer than those in the first group, and the third group is made up of varieties with a medium or long cycle. These are ISRIZ 04, ISRIZ 05, ISRIZ 06, ISRIZ 07, ISRIZ 12, SAHEL177 and SAHEL 201. The second group is made up of SAHEL108 and NERICA-S-44, which are considered to have a short cycle, but are slightly longer than those in the first group, and the third group is made up of varieties with a medium or long cycle. These are ISRIZ 04, ISRIZ 05, ISRIZ 06, ISRIZ 07, ISRIZ 12, SAHEL177 and SAHEL 201. These medium and long cycle varieties, if not sown at the right date, can easily suffer the effects of low temperatures. These results are in line with those of Faghani et al. (2011), who showed that timely sowing allows rice plants to better express their potential and to better adapt to extreme temperature conditions (cold and heat). Similarly, Vange and Obi (2006) showed in their study that NERICA varieties sown between June and July in Nigeria favour good adaptation, but studies under our fluctuating climatic conditions show that sowing between July and August favours the adaptation of ISRIZ varieties.

**Conclusion**

The results of this on-station study highlighted newly released rice varieties that showed good adaptation to the fluctuating climatic conditions in the Senegalese Institute of Agricultural Research (ISIRIZ) varieties released by the Institut Sénégalais de Recherches Agricoles would adapt better to these climatic fluctuations and would allow for double cropping. However, the climatic conditions, mainly the low temperatures (12-18°C) associated with each sowing date, had a negative effect on the vegetative behaviour of the varieties. Similarly, the choice of sowing method is a very important element to promote good rice productivity. The timely cultivation of rice paddy under the fluctuating climatic conditions in the SRV can be effective for the practice of double cropping, but also improve productivity, so that the choice of a better sowing date and suitable sowing method can allow rice to benefit from the better conditions related to these sowing dates to accommodate the low temperatures. In times of low temperatures, the practice of transplanting promotes a better adaptation of rice paddy. In the future, it would be desirable to carry out a modelling study to predict the behaviour of these varieties over a long period of 10 to 20 years.

**CONFLICT OF INTERESTS**

The authors have not declared any conflict of interests.

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