

## Interannual Rainfall Variability and Its Impacts on Cropping Patterns in Malang Regency, Indonesia

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### ABSTRACT

El Niño and La Niña events typically affect rainfall patterns and water availability for plants, especially in rainfed and upland farming systems. This study examines year-to-year variations in rainfall associated with El Niño and La Niña events, as well as their impacts on potential planting seasons and on the management of food-crop planting patterns in Malang Regency. The rainfall data used in this analysis are from the Karangploso and Karangates climatology stations for the period 2012–2024. The analysis reveals that over the past 13 years, El Niño events have not altered the duration of the dry or rainy seasons in Lawang Subdistrict, nor have they shortened the rainy-season duration by 1 decade relative to normal conditions in Donomulyo Subdistrict. However, La Niña events can prolong the rainy season by 3–13 decades in Lawang Subdistrict or 2–14 decades in Donomulyo Subdistrict. The average potential planting time at the research location is 210 days in Lawang Subdistrict and 240 days in Donomulyo Subdistrict, posing a significant risk of planting rice across two growing seasons. By selecting adaptive crops and managing planting patterns, it could be possible to plant three times using a rice-corn-beans pattern during the planting seasons in the Lawang Subdistrict or a rice-corn and rice-beans pattern in the Donomulyo Subdistrict. During La Niña events, crop pattern management can be more flexible, and planting intensity can be increased by 3–4 times through effective crop pattern management.

**Keywords:** change of growing season, cropping management, rainfall analysis, rainfall pattern, planting schedule

## Introduction

Upland farming is a planting technique practiced in dry or arid areas with limited rainfall, while rainfed rice fields are planted in areas with drainage systems that prevent flooding. Both systems require a specialized rainwater-use technique known as rainwater harvesting, and the farming system is called runoff agriculture (Garg et al., 2022; Ingle et al., 2024; Narsimlu et al., 2024; Notohadiprawiro, 1989; Rejekiningrum et al., 2022; Soriano & Herath, 2020).

The area of dry land identified in Indonesia is 144,473,966 ha, spread across lowlands and highlands, and with both wet and dry climates. The potential for dry land that can be used for food crops and vegetables is around 37,939,046 ha, while the estimated area of dry land utilized for food crops and vegetables is 5,531,022 ha (Tim BBSDLP, 2014). Thus, there is still a large area of dry land that has not been utilized for agricultural cultivation, especially food crops. Meanwhile, there is no detailed data on the extent of rainfed rice fields.

As rainfed and dryland agriculture are highly dependent on rainfall, shifts in rainfall patterns, changes in rainfall magnitude, and changes in air temperature due to climate anomalies and climate change can significantly impact agricultural production (Irawan, 2006; Kang et al., 2009). A drastic decrease in rainfall due to the El Niño climate anomaly can cause drought-induced crop failure, while an increase in rainfall due to the La Niña climate anomaly can cause flooding and stimulate the growth of plant-disturbing organisms (Irawan, 2006). The variability of rainfall due to climate anomalies has at least two impacts on rainfed rice farming and dryland agriculture: shifts in the start and end of the planting season, changes in the duration of the potential planting period, and disruptions in soil water availability.

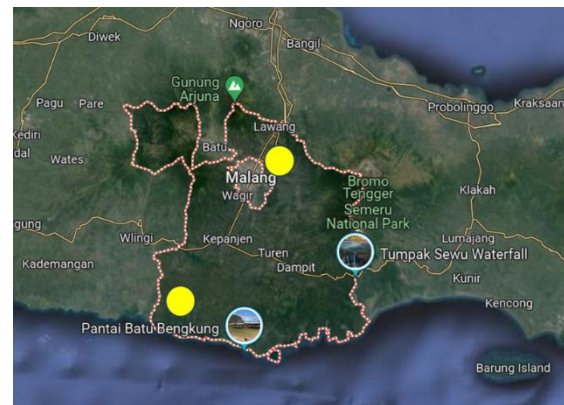
To mitigate the negative impacts and leverage the positive impacts of rainfall variability, strategic steps are needed,

including planning planting times, arranging appropriate planting patterns, and selecting adaptive commodities. Naylor et al. (2001, 2007) stated that determining the start of the rice planting season is an important strategy in agricultural cultivation in Indonesia, especially for food and other seasonal crops. The paper aims to present a picture of interannual rainfall variability and its impact on changes in planting schedules and cropping patterns, using a case study in Malang Regency.

## Materials and Methods

### Research Location

The research was conducted in the Lawang and Donomulyo Subdistricts of Malang Regency (Figure 1).



**Fig. 1.** Location of this research in Malang Regency.

### Data Collection and Climate Analysis

The climatological data used are daily rainfall and air temperature from the Karangpulo Climatology Station and the Karangates Geophysics Station, covering 2012–2024. The data is accessed from the page [www.data-online/bmkg.go.id](http://www.data-online/bmkg.go.id). The daily data is then compiled into 10-day and monthly data. The analysis of the monthly rainfall data focuses on the average rainfall pattern. The analysis of the 10-day data aims to determine the history of the onset dates of the rainy and dry seasons for each observation year. This early-season variability is then associated with El Niño, La Niña, and Normal years. This leads to a discussion of interannual variability at the start of the rainy and dry seasons, as an

impact of El Niño and La Niña events, within the broader context of climate anomalies. Data analysis was also conducted to produce a 10-day average rainfall value, which was then used for water balance analysis and cropping pattern planning.

*Groundwater Balance Analysis and Cropping Pattern Guidelines*

This land water balance calculation was carried out to develop alternative cropping patterns for upland or rainfed paddy, maize, and beans by adopting a bookkeeping system calculation technique (Thorntwaite & Mather, 1957) modified at a 10-day interval (Pramudia, 1989; Pramudia et al., 2013) and taking into account the rainfall requirements for paddy, maize, and beans used in the Integrated Cropping Calendar Information System developed by the Ministry of Agriculture (Pramudia et al., 2021a; Runtunuwu et al., 2013; Wahyudi et al., 2021). The procedure for calculating the water balance is as follows:

- Column-1: decades or 10-day increment periods, sequentially from January I to December III
- Column-2: 10-day rainfall (mm)
- Column-3: climatological season, based on the amount of rainfall intensity
- Column-4: potential evapotranspiration (PET) (mm)

$$ET_o = \frac{0.408 \Delta (Rn - G) + \gamma \left( \frac{900}{T + 273.15} \right) U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 U_2)} \tag{1}$$

$$PET = kc \times ET_o \tag{2}$$

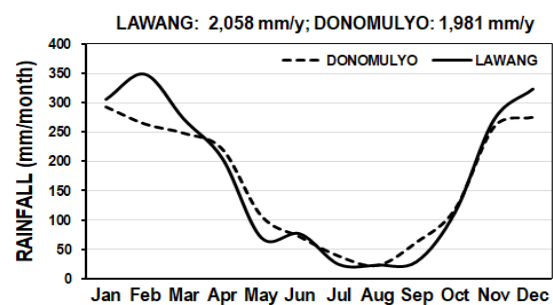
- Column-5: R-PET (mm)
- Column-6: potential of paddy planting periods
- Column-7: potential of maize planting periods
- Column-8: potential of bean planting periods
- Column-9–11: the alternative of cropping patterns

**Results and Discussion**

*Rainfall Pattern and Interannual Variability of Rainfall Seasons.*

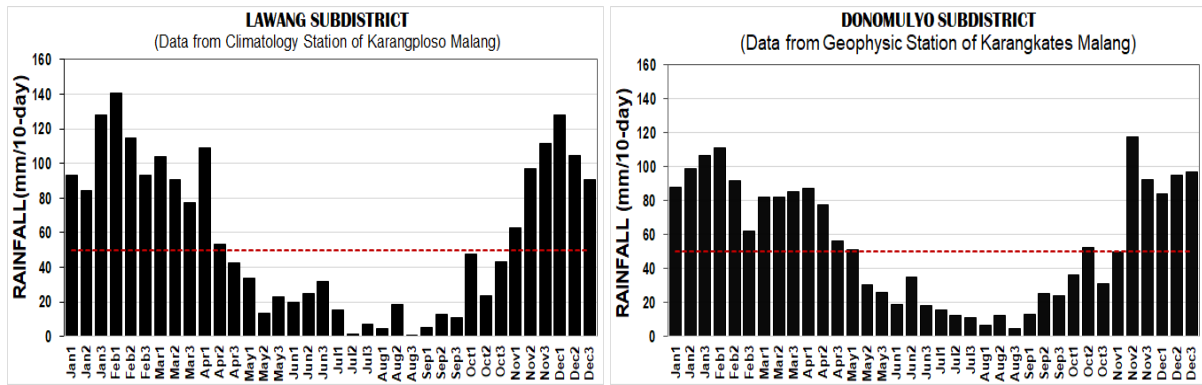
Figure 2 illustrates the average monthly rainfall patterns in Lawang and Donomulyo Subdistricts, Malang Regency. The Lawang Subdistrict receives an annual rainfall total of 2,058 mm/y, with six wet

months exceeding 200 mm per month and five dry months below 100 mm per month. The month with the highest rainfall is February, averaging 348 mm/month, whereas August has the lowest rainfall, averaging 23 mm/month. With characteristics similar to those of the Donomulyo Subdistrict, the Donomulyo Subdistrict experiences an annual rainfall total of 1,981 mm/y, characterized by six wet months with an intensity exceeding 200 mm per month and four dry months with an intensity below 100 mm per month. The month with the highest rainfall is January, averaging 293 mm/month, whereas August has the lowest rainfall, averaging 23 mm/month.



**Fig. 2.** Rainfall pattern at the research location, Lawang and Donomulyo Subdistricts, Malang Regency.

The rainfall pattern in these areas is either a simple wave (Pramudia et al., 2022) or monsoonal (Kadarsah, 2007), indicating varying rainfall intensity between the wet and dry periods. According to the agroclimate resource map (Pramudia et al., 2021b; Purnamayani, 2024; Susanti et al., 2021), Lawang and Donomulyo Subdistricts fall within agroclimate zone B.II.2, which corresponds to a moderate climate category with an annual rainfall range of 1,500–2,500 mm/y. In conventional agriculture, when the growing season begins during the wet period, it is ideal to plant with a potential planting index of 200% using a rice-rice pattern. This pattern can be applied under normal conditions, but if rainfall is low or high, it is necessary to adjust to the available water.



**Fig. 3.** The fluctuation of rainfall intensity means the periods of 2012–2024.

The planting pattern can be adjusted to the available water conditions.

Figure 3 illustrates fluctuations in the average 10-day rainfall during 2012–2024 in the study area. The figure indicates that the average decadal rainfall fluctuation at Lawang Subdistrict is 17 decadal with rainfall intensity greater than or equal to 50 mm/10-day, and 19 decadal with rainfall intensity less than 50 mm/10-day. According to BMKG (2017), a value of 50 is the threshold for identifying the rainy or dry season. Thus, the average duration of the rainy Season at Lawang Subdistrict is 17 decades, and the duration of the dry Season is 19 decades. In Donomulyo Subdistrict, there are 19 decadal periods with rainfall intensity of 50 mm or more over 10 days, and 17 decadal periods with rainfall intensity below 50 mm. However, the average duration of the rainy season at Donomulyo Subdistrict is 18 decades, and the duration of the dry season is 18 decades.

Figure 4 illustrates the fluctuations between the beginning of the rainy season and the beginning of the dry season in Lawang and Donomulyo Subdistricts from 2012 to 2024. According to the criteria from BMKG (BMKG, 2017), the rainfall analysis describes that in Lawang Subdistrict, the rainy season period in normal years is December I, while in El Niño years, it varies from November I to December I, and in La Niña years, it varies from October I to November I. The dry season period in normal years ranges from April II to May II; in El Niño years, from March III to May II; and in La Niña years, from April II to July II. In the Donomulyo Subdistrict, the rainy season period in normal years ranges from November II to December II; in El Niño years, from November I to December III; and in La Niña years, from September II to November III. The dry season period in normal years ranges from February I to May I; in El Niño years, from February II to May II; and in La

Kecamatan Lawang													Kecamatan Donomulyo													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Climate Anomaly (Dominant)*
2012	w	w	w	w	w	w	w	w	w	w	w	w	2012	w	w	w	w	w	w	w	w	w	w	w	w	Normal
2013	w	w	w	w	w	w	w	w	w	w	w	w	2013	w	w	d	d	d	d	d	d	d	d	d	d	Normal
2014	w	w	w	w	w	w	w	w	w	w	w	w	2014	w	w	w	d	d	d	d	d	d	d	d	d	El-Niño
2015	w	w	w	w	w	w	w	w	w	w	w	w	2015	w	w	w	w	w	w	w	w	w	w	w	w	El-Niño
2016	w	w	w	w	w	w	w	w	w	w	w	w	2016	w	w	w	w	w	w	w	w	w	w	w	w	La-Niña
2017	w	w	w	w	w	w	w	w	w	w	w	w	2017	w	w	w	w	w	w	w	w	w	w	w	w	La-Niña
2018	w	w	w	w	w	w	w	w	w	w	w	w	2018	w	w	w	w	w	w	w	w	w	w	w	w	El-Niño
2019	w	w	w	w	w	w	w	w	w	w	w	w	2019	w	w	w	w	w	w	w	w	w	w	w	w	Normal
2020	w	w	w	w	w	w	w	w	w	w	w	w	2020	w	w	w	w	w	w	w	w	w	w	w	w	La-Niña
2021	w	w	w	w	w	w	w	w	w	w	w	w	2021	w	w	w	w	w	w	w	w	w	w	w	w	La-Niña
2022	w	w	w	w	w	w	w	w	w	w	w	w	2022	w	w	w	w	w	w	w	w	w	w	w	w	La-Niña
2023	w	w	w	w	w	w	w	w	w	w	w	w	2023	w	w	w	w	w	w	w	w	w	w	w	w	El-Niño
2024	w	w	w	w	w	w	w	w	w	w	w	w	2024	w	w	w	w	w	w	w	w	w	w	w	w	La-Niña

**Fig. 4.** The interannual variability of rainfall seasons at research locations in Lawang and Donomulyo Subdistricts, Malang Regency. History of ENSO events according to Climate Prediction Center (2024) and Golden Gate Weather Services (2024).

Niña years, from April II to June III. Therefore, at Lawang Subdistrict, the duration of the rainy season varies from 14 decades in the El Niño year 2020 to 27 decades in the La Niña year 2016. While at Donomulyo Subdistrict, the duration of the rainy season varies from 7 decades in the El Niño year 2014 to 28 decades in the La Niña year 2016.

*The Cropping Pattern Management*

Table 1 presents the parameters for mean rainfall and mean potential evapotranspiration in the water balance calculation, and a diagram of cropping pattern management in Lawang Subdistrict, Malang Regency. The diagram contains a recommended potential planting calendar and cropping pattern. According to the diagram, the average beginning of the rainy

season is in November I. However, the potential first paddy planting season could begin earlier in October I, with soil tillage starting in September III. The second planting season could begin in February I for paddy crops, or in January III for maize crops. In the middle of maize growth, it could still plant beans in February III.

Table 2 presents similar parameters and a diagram at Donomulyo Subdistrict, Malang Regency. The diagram contains a recommended potential planting calendar and cropping pattern. According to the diagram, the average beginning of the rainy season is in November II. However, the potential first paddy planting season could begin earlier in October II, with soil tillage in October I. The second planting season could begin in February II for paddy crops or in February I for maize crops. In the

**Table 1.** Water balance calculation and cropping pattern management in Lawang Subdistrict (590 m asl), Malang Regency.

10-Day	Rainfall (R)	PET	Season	R-PET	Crop1	Crop2	Crop3	Crop pattern1	Crop pattern2
Jul 1	15.4	32.5	Dry	-17.1	-	-	-	-	-
Jul 2	1.3	33.8	Dry	-32.5	-	-	-	-	-
Jul 3	7.1	37.4	Dry	-30.2	-	-	-	-	-
Aug 1	4.3	35.3	Dry	-31.0	-	-	-	-	-
Aug 2	18.5	37.0	Dry	-18.6	-	-	-	-	-
Aug 3	0.2	41.1	Dry	-40.9	-	-	-	-	-
Sep 1	5.3	39.8	Dry	-34.5	-	-	-	-	-
Sep 2	12.6	39.8	Dry	-27.1	-	-	-	-	-
Sep 3	10.6	40.9	Dry	-30.3	-	-	-	Soil tillage	Soil tillage
Oct 1	47.4	42.5	Dry	4.9	Paddy 1	Maize	Beans 1	Paddy1	Paddy
Oct 2	23.3	43.4	Dry	-20.2	Paddy 2	Maize	Beans 2	Paddy1	Paddy
Oct 3	43.0	49.2	Dry	-6.3	Paddy 3	Maize	Beans 3	Paddy1	Paddy
Nov 1	62.5	42.9	Rainy	19.5	Paddy 4	Maize	Beans 4	Paddy1	Paddy
Nov 2	97.2	43.6	Rainy	53.6	Paddy 5	Maize	Beans 5	Paddy1	Paddy
Nov 3	111.3	43.1	Rainy	68.2	Paddy 6	Maize	Beans 6	Paddy1	Paddy
Dec 1	127.9	42.0	Rainy	85.9	Paddy 7	Maize	Beans 7	Paddy1	Paddy
Dec 2	104.6	39.6	Rainy	64.9	Paddy 8	Maize	Beans 8	Paddy1	Paddy
Dec 3	90.5	43.5	Rainy	47.0	Paddy 9	Maize	Beans 9	Paddy1	Paddy
Jan 1	93.3	42.7	Rainy	50.7	Paddy 10	Maize	Beans 10	Paddy1	Paddy
Jan 2	84.1	43.2	Rainy	40.9	Paddy 11	Maize	Beans 11	Paddy1	Paddy
Jan 3	127.8	47.7	Rainy	80.1	Paddy 12	Maize 1	Beans 12	Soil tillage	Maize
Feb 1	140.7	43.2	Rainy	97.6	Paddy 13	Maize 2	Beans 13	Paddy2	Maize
Feb 2	114.7	43.4	Rainy	71.2	Paddy 14	Maize 3	Beans 14	Paddy2	Maize
Feb 3	92.9	34.2	Rainy	58.7	Paddy 15	Maize 4	Beans 15	Paddy2	Maize Beans
Mar 1	104.2	42.9	Rainy	61.2	Paddy 16	Maize 5	Beans 16	Paddy2	Maize Beans
Mar 2	90.3	42.6	Rainy	47.7	Paddy 17	Maize 6	Beans 17	Paddy2	Maize Beans
Mar 3	77.4	44.8	Rainy	32.6	Paddy 18	Maize 7	Beans 18	Paddy2	Maize Beans
Apr 1	108.9	40.7	Rainy	68.2	Paddy 19	Maize 8	Beans 19	Paddy2	Maize Beans
Apr 2	53.2	38.3	Rainy	14.9	Paddy 20	Maize 9	Beans 20	Paddy2	Maize Beans
Apr 3	42.3	38.3	Dry	3.9	Paddy 21	Maize 10	Beans 21	Paddy2	Beans
May 1	33.5	35.8	Dry	-2.2	-	Maize 11	Beans 22	Paddy2	Beans
May 2	13.1	34.3	Dry	-21.3	-	-	-	-	-
May 3	22.9	37.6	Dry	-14.8	-	-	Beans 1	-	-
Jun 1	19.7	34.3	Dry	-14.6	-	-	-	-	-
Jun 2	24.5	33.6	Dry	-9.1	-	-	Beans 1	-	-
Jun 3	31.8	32.9	Dry	-1.1	-	Maize	Beans 2	-	-

**Table 2.** Water balance calculation and cropping pattern management in Donomulyo Subdistrict (285 m asl), Malang Regency.

10-Day	Rainfall (R)	PET	Season	R-PET	Crop1	Crop2	Crop3	Crop pattern1	Crop pattern2
Jul1	15.4	32.7	Dry	-17.3	-	-	-	-	-
Jul2	12.3	34.0	Dry	-21.8	-	-	-	-	-
Jul3	10.7	37.7	Dry	-27.0	-	-	-	-	-
Agu1	6.5	35.6	Dry	-29.1	-	-	-	-	-
Agu2	12.0	37.3	Dry	-25.4	-	-	-	-	-
Agu3	4.3	41.6	Dry	-37.3	-	-	-	-	-
Sep1	13.0	40.2	Dry	-27.1	-	-	-	-	-
Sep2	25.1	40.4	Dry	-15.3	-	Maize	Beans 1	-	-
Sep3	24.1	41.5	Dry	-17.4	-	-	Beans 2	-	-
Okt1	35.9	43.0	Dry	-7.1	-	Maize	Beans 3	Soil Tillage	Soil Tillage
Okt2	52.1	43.8	Dry	8.3	Paddy 1	Maize	Beans 4	Paddy1	Paddy
Okt3	31.0	49.6	Dry	-18.6	Paddy 2	Maize	Beans 5	Paddy1	Paddy
Nov1	49.6	43.5	Dry	6.1	Paddy 3	Maize	Beans 6	Paddy1	Paddy
Nov2	117.3	44.0	Rainy	73.3	Paddy 4	Maize	Beans 7	Paddy1	Paddy
Nov3	92.2	43.5	Rainy	48.7	Paddy 5	Maize	Beans 8	Paddy1	Paddy
Des1	84.0	43.4	Rainy	40.6	Paddy 6	Maize	Beans 9	Paddy1	Paddy
Des2	95.0	41.8	Rainy	53.3	Paddy 7	Maize	Beans 10	Paddy1	Paddy
Des3	96.4	46.4	Rainy	50.0	Paddy 8	Maize	Beans 11	Paddy1	Paddy
Jan1	87.8	43.3	Rainy	44.5	Paddy 9	Maize	Beans 12	Paddy1	Paddy
Jan2	98.7	43.7	Rainy	55.0	Paddy 10	Maize	Beans 13	Paddy1	Paddy
Jan3	106.4	48.3	Rainy	58.1	Paddy 11	Maize	Beans 14	Paddy1	Paddy
Feb1	110.6	43.7	Rainy	66.9	Paddy 12	Maize 1	Beans 15	Soil Tillage	Maize
Feb2	91.4	44.0	Rainy	47.4	Paddy 13	Maize 2	Beans 16	Paddy2	Maize
Feb3	61.9	34.7	Rainy	27.2	Paddy 14	Maize 3	Beans 17	Paddy2	Maize
Mar1	81.6	43.5	Rainy	38.1	Paddy 15	Maize 4	Beans 18	Paddy2	Maize
Mar2	81.7	43.1	Rainy	38.6	Paddy 16	Maize 5	Beans 19	Paddy2	Maize Beans
Mar3	84.8	45.4	Rainy	38.5	Paddy 17	Maize 6	Beans 20	Paddy2	Maize Beans
Apr1	87.2	41.0	Rainy	46.1	Paddy 18	Maize 7	Beans 21	Paddy2	Maize Beans
Apr2	77.2	38.8	Rainy	38.5	Paddy 19	Maize 8	Beans 22	Paddy2	Maize Beans
Apr3	56.2	38.6	Rainy	17.6	Paddy 20	Maize 9	Beans 23	Paddy2	Maize Beans
Mei1	51.2	36.1	Rainy	15.1	Paddy 21	Maize 10	Beans 24	Paddy2	- Beans
Mei2	30.0	34.7	Dry	-4.6	-	Maize 11	Beans 25	Paddy2	- Beans
Mei3	25.9	37.9	Dry	-12.0	-	Maize 12	Beans 26	-	- Beans
Jun1	18.5	34.5	Dry	-16.0	-	-	-	-	-
Jun2	34.6	33.7	Dry	0.8	-	Maize	Beans 1	-	-
Jun3	18.2	33.1	Dry	-14.9	-	-	-	-	-

middle of maize growth, it could still plant beans in March II.

**Conclusion**

The rainfall data used in this analysis are from the Karangploso and Karangates climatology stations for the period 2012–2024. Historical rainfall data show that El Niño and La Niña events typically affect rainfall seasonality and plant water availability. The analysis reveals that over the past 13 years, El Niño events have not altered the duration of the dry or rainy seasons in Lawang Subdistrict,

nor have they shortened the rainy season by 1 decade relative to normal conditions in Donomulyo Subdistrict. However, La Niña events can prolong the rainy season by 3–13 decades in Lawang Subdistrict or 2–14 decades in Donomulyo Subdistrict. The average potential planting time at the research location is 220 days in Lawang Subdistrict and 240 days in Donomulyo Subdistrict, posing a significant risk of planting rice across two growing seasons. By selecting adaptive crops and managing planting patterns, it may be possible to plant

three times in a rice-corn-beans pattern across the planting seasons in both the Lawang and Donomulyo Subdistricts. During La Niña events, crop pattern management can be more flexible, and planting intensity can be increased by 3–4 times through effective crop pattern management.

Nevertheless, variations in the timing of seasonal onset remain an important consideration. Delayed onset of the rainy season may postpone planting activities, while an earlier onset can allow earlier planting dates. Inaccurate timing of planting relative to seasonal onset may increase the likelihood of seedling establishment failure due to insufficient soil moisture or uneven rainfall distribution. Consequently, synchronizing the cropping calendar with projected seasonal onset is essential for reducing climate-related risks, improving crop establishment, and enhancing the overall efficiency of cropping systems under La Niña conditions.

### Acknowledgements

Thanks to the Indonesia Endowment Fund for Education Agency, through the Riset Inovasi untuk Indonesia Maju (RIIM) scheme, for providing funds to implement this activity. Thanks, and we have also been transferred to the National Research and Innovation Agency of the Republic of Indonesia (Badan Riset dan Inovasi Nasional Indonesia, BRIN), which has provided the opportunity to work on the research. The exact words were conveyed to the Agriculture Service of Malang Regency, East Java, extension workers, farmers, and all parties who have helped.

### Conflict of Interest

The authors declare that they have no conflict of interest.

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