

## USING GLOBAL CLIMATE INDICES TO PREDICT RAINFALL AND SUGARCANE PRODUCTIVITY IN DRYLANDS OF BANYUWANGI, EAST JAVA, INDONESIA

### *Penggunaan Indeks Iklim Global untuk Memprediksi Curah Hujan dan Produktivitas Tebu di Lahan Kering Banyuwangi, Jawa Timur*

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### ABSTRACT

In Indonesia, sugarcane (*Saccharum officinarum* L.) is mostly cultivated in drylands, thus depending on rainfall for crop growth and development. Rainfall is an essential factor affecting sugarcane productivity. The global climate indices can be used to investigate potential of rainfall within a given area and its relationship with crop productivity. This research aimed to analyze the relationship between the global climate index, rainfall, and sugarcane productivity in drylands near Glenmore sugar mill, i.e., Benculuk and Jolondoro, Banyuwangi, East Java, Indonesia. The global climate index data used were the Southern Oscillation Index (SOI) and Sea Surface Temperature (SST) between 1995 and 2014. Results of this research showed that SOI and SST can be used to predict the rainfall in both Benculuk and Jolondoro. Rainfall (y) can be predicted with SST data (x) using the equation of  $y = -352.49x + 7724.1$  in Benculuk and  $y = -107.32 + 3443.4$  in Jolondoro, as well as with SOI data (x) using the equation of  $y = 38.664x + 1555.1$  in Benculuk and  $y = 10.541x + 1567.8$  in Jolondoro. Sugarcane productivity (y) in Jolondoro can be predicted using data of total rainfall (x) between October and March with the following equation:  $y = -0.1672x + 1157.3$ . This equation can be used by sugar mills, sugarcane growers, and other sugarcane-relevant stakeholders for determining the appropriate growing season.

[**Keywords:** Banyuwangi, global climate indices, modelling, rainfall, sugarcane productivity]

### ABSTRAK

Sebagian besar tebu (*Saccharum officinarum* L.) di Indonesia dibudidayakan di lahan kering sehingga bergantung pada hujan untuk pertumbuhan dan perkembangan tanaman. Curah hujan merupakan salah satu faktor penting yang memengaruhi produktivitas tebu. Indeks iklim global dapat digunakan untuk mengetahui potensi curah hujan dan hubungannya dengan produktivitas tanaman. Penelitian ini bertujuan untuk menganalisis hubungan antara indeks iklim global, curah hujan,

dan produktivitas tebu di lahan kering dekat Pabrik Gula Glenmore, yaitu Benculuk dan Jolondoro di Banyuwangi, Jawa Timur. Data indeks iklim global yang digunakan yaitu Southern Oscillation Index (SOI) dan Sea Surface Temperature (SST) tahun 1995-2014. Hasil penelitian menunjukkan bahwa SOI dan SST dapat digunakan untuk memprediksi curah hujan di Benculuk dan Jolondoro. Curah hujan (y) dapat diprediksi dengan data SST (x) menggunakan persamaan  $y = -352,49x + 7724,1$  di Benculuk dan  $y = -107,32 + 3443,4$  di Jolondoro, serta dengan data SOI (x) menggunakan persamaan  $y = 38,664x + 1555,1$  di Benculuk dan  $y = 10,541x + 1567,8$  di Jolondoro. Produktivitas tebu (y) di Jolondoro dapat diprediksi dengan data curah hujan total (x) Oktober-Maret menggunakan persamaan  $y = -0,672x + 1157,3$ . Persamaan ini dapat digunakan oleh pabrik gula, petani tebu, dan mitra pengguna lainnya untuk menentukan musim tanam tebu yang tepat.

[**Kata Kunci:** Banyuwangi, curah hujan, indeks iklim global, pemodelan, produktivitas tebu]

### INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is one of the essential staple crops in Indonesia, as the main sugar producer. Sugar production in Indonesia fluctuates over time, but it tends to decrease (FAOSTAT 2020; Putra et al. 2016; Sulaiman et al. 2019; Toharisman and Triantarti 2016). Several factors causing such declines are degradation of sugarcane cultivar, poor cultivation management, climate variability, and low mill efficiency (Dardak 2012; Ranomahera 2013). For instance, climatic factors such as rainfall and water availability play an essential role in sugarcane cultivation and impact sugarcane yield. Sugarcane requires a large amount of water during its growth (van Dillewijn 1952;

Pawirosemadi 2011), yet several plantations in Indonesia are located in dryland areas that strongly depend on rainfall (Triantarti 2014). Unfortunately, those locations are unreachable by irrigation canals. This condition is even exacerbated by climate change (Directorate General of Estate Crops of Indonesia 2016).

Currently, climate factors are progressively unpredictable, particularly rainfall. Climate change is projected to result in change of rainfall pattern (Dhillon and von Wuehlisch 2013). A report by Toharisman (2013) indicated that rainfall had occurred intensively in July–August 2013, which normally, it should be the dry season period. On the contrary, Irawan (2002) reported a 39% decrease in rainfall after the El-Nino event in 1997. Nugroho et al. (2013) observed that Indonesia consistently experiences dry season and drought during El-Nino Southern Oscillation (ENSO) cycles. Consequently, drought often occurs in several areas in Indonesia, which further hampering sugarcane productivity.

Drought can also lead to the delay of the growing season (Hamada et al. 2002; McPhaden 1999; Our World in Data 2020). The adverse effects of drought to sugarcane production associated climate change can be greater in the countries with high dependency on rainfall with limited or no proper irrigation conditions and/or that have poor mitigation systems (Thornton et al. 2009), such as Indonesia. Therefore, under climate change conditions, there is a need to adjust the growing season, meaning that the growing season can be started earlier or later than the usual growing season. Sugarcane growers need to decide the most appropriate time to start the growing season, depending on the real-time and prediction of climate (Lassa et al. 2014).

Rather than the global climate indices (GCI), in Indonesia, rainfall is often used as a factor to find out the right growing season and to predict crop production. However, GCI can also be used to determine the amount of rainwater and its relationship to crop production. Based on a study in Gunung Kidul, Yogyakarta, Nugroho

et al. (2013) found a more significant relationship between GCI and crop production than the relationship between rainfall and crop production. Previous studies also showed a close relationship between GCI and crop production in Indonesia (Amien et al. 1996; Irawan 2002; Kirono and Khakim 1999; Naylor et al. 2002; Nugroho et al. 2013). The present study aimed (1) to analyze the relationship between GCI and sugarcane productivity to mitigate climate change effects on sugarcane cultivation, and (2) to generate the model that can be used to predict sugarcane productivity using GCI values.

## MATERIALS AND METHODS

### Site Description

The study was carried out in the dryland sugarcane area of 700 ha in Benculuk (8°28'39" S, 114°14'20" E) and 450 ha in Jolondoro (8°20'14" S, 114°03'04" E), located near Glenmore sugar mill in Banyuwangi, East Java, Indonesia from March to December 2015. Both locations were selected since they represented dryland sugarcane cultivation in large areas. Sugarcane relies heavily on rainwater at these two locations since there is no irrigation. Sugarcane planting is performed in the early rainy season. However, if there is no rainfall during the planting period, a borehole can be made in some plantation points as an irrigation source. Both Benculuk and Jolondoro are under state-owned plantation company supervision, certified as state land or *Hak Guna Usaha* (HGU).

Surrounded by Ijen and Gunitir mountains on the north side allows both Benculuk and Jolondoro to have an average land-slope of 5% southward. The soil in Benculuk and Jolondoro is dominated by clay and sand, respectively. Sugarcane cultivars grown in both areas were varied, i.e., PS 881, PS 862, Kidang Kencana, Bululawang, and local cultivars, but Bululawang was the most dominant variety (Table 1). Mixed sugarcane

**Table 1. Description of research sites in the area of Glenmore sugar mill, Banyuwangi, East Java.**

| Characteristics                                   | Location                  |                           |
|---|---------------------------|---------------------------|
|   | Benculuk                  | Jolondoro                 |
| Land topography                                   | 95% flat, 5% hilly        | 65% flat, 35% hilly       |
| Climate type (Oldeman)                            | C3                        | C3                        |
| Dominant soil texture                             | Clay                      | Sand                      |
| Sugarcane cultivar                                | Bululawang, PS 881, HW    | Bululawang, PS 881, HW    |
| Distance to sea                                   | 20 km to the Indian ocean | 30 km to the Indian ocean |
| Range of soil pH                                  | 4.88–5.35 (acid)          | 4.36–5.38 (acid)          |
| Range of total soil N (%)                         | 0.1–0.12 (moderate)       | 0.03–0.06 (very low)      |
| Range of soil P <sub>2</sub> O <sub>5</sub> (ppm) | 34–51 (moderate)          | 28–57 (moderate)          |
| Range of soil K <sub>2</sub> O (ppm)              | 613–955 (very high)       | 113–153 (high)            |

Note: classification class in parentheses is based on Prasetyo (2009).

cultivars were found in the field; thus, it was difficult to obtain valid data of sugarcane productivity of each cultivar in each plot. Therefore, we used the average data of sugarcane productivity in Benculuk and Jolondoro, rather than each plot data.

According to the result of chemical soil analysis, both Benculuk and Jolondoro have a low soil pH. Benculuk has a moderate total soil N and  $P_2O_5$ , and very high soil  $K_2O$ . Meanwhile, total soil N,  $P_2O_5$ , and  $K_2O$  in Jolondoro are categorized as very low, moderate, and high, respectively.

Some materials used were 15 soil samples in each location, topographic maps (*Peta Rupa Bumi Indonesia*, RBI), a set of equipment for the field survey, rainfall data, Global Climate Indices (GCI) data of Southern Oscillation Index (SOI) and Sea Surface Temperature (SST), as well as historical sugarcane production data in both Jolondoro and Benculuk.

### GCI Data

The GCI data used in the present study were a monthly average data of the SOI and SST during the periods of 1995–2014. The SOI and SST were selected since they can be an indicator for El-Nino and La-Nina occurrences in Indonesia. The SOI data are free and downloaded from the Australian Bureau of Meteorology (<http://www.bom.gov.au/climate/current/soihtml.shtml>), whereas SST data were collected from the Japan Meteorological Agency (JMA), both of them are available online. Although Indonesia had the SST data, the data from JMA were more reliable, particularly the data from Indian Ocean Basin-Wide (IOBW). The SST includes three El-Nino monitoring areas, i.e., Niño.3 (5°N–5°S, 150°–90°W), Niño.West (0–15°N, 130°–150°E), and the IOBW (20°S–20°N, 40°–100° E) (Figure 1). The SOI and SST values were averaged for each month during the six months of rainy season (October to March) and the following six months of dry season (April to September). Data from the three El-Nino monitoring areas were

integrated with Principal Component Analysis (PCA). In this study, only Principal Components (PCs) index above 70% of cumulative proportion of variance were used for further data analysis (Nugroho et al. 2013).

### Rainfall Data

The average monthly and daily rainfall data between 1995–2014 of nearby weather stations were obtained from the Irrigation Office in Banyuwangi. Since this study would discover the relationship between GCI and rainfall within Indonesia, the data were analyzed by splitting them into two seasons, i.e., total rainfall during the rainy season (October to March) for crop growth and dry season (April to September) for crop maturity period.

### Sugarcane Productivity Data

Sugarcane productivity data were complemented by the data of cultivar and its maturity type, as genetic factors are known to affect sugarcane productivity. The data of sugarcane productivity between 1995–2014 were collected from Jolondoro and Benculuk stations (belongs to PT Perkebunan Nusantara XI) and analyzed with a low-pass spectral smoothing filter to minimize data error (outlier), such as a mistake by field officers in reading and/or transferring the data in the log book (manual). For the analysis, residual sugarcane productivity was calculated by the following equation (Nugroho et al. 2013):

$$y_{\text{residual}} = \frac{y_{\text{observeb}}}{y_{\text{smoothed}}} - 1 \quad (1)$$

$y$  = sugarcane productivity

Residual sugarcane productivity data were correlated with GCI data, i.e., SOI and SST, rainfall in rainy season (October–March) and dry season (April–September) to



Fig. 1. Three areas for data monitoring of Global Climate Indices (GCI), adapted from Nugroho et al. (2013).

understand the influence of the rainy and dry season as well as GCI on sugarcane productivity. Overall, the regression analysis in this research was carried out between (1) GCI data and rainfall; (2) GCI data and sugarcane productivity; as well as (3) rainfall and sugarcane productivity. If there is a strong correlation, shown by  $R^2$  value above 0.7 between parameters, the analysis results that are expressed in the form of equations (Equation 2) can predict annual rainfall and sugarcane productivity.

$$(2) \quad y = ax + b$$

$y$  = rainfall or sugarcane productivity in year  $i$

$x$  = prediction of GCI value in year  $i$

$a$  and  $b$  = constants obtained from regression analysis

## RESULTS AND DISCUSSION

### Global Climate Indices

The PCA score of GCI parameters such as SST and SOI is presented in Table 2. Table 2 (at the bottom of the table) shows the PCA calculation result of SST values from three monitoring areas based on period of 1993–2009. This data period was used to obtain PC value only and was not related to the period of the next calculation. PCA index that reached 0.70 (PC2) can be used as a data series

for the next correlation process using GCI, rainfall, and productivity data from the same year (Nugroho et al. 2013).

### Rainfall Characteristic

Based on 20-years (1995–2014) average rainfall data, the peak month of the rainy and dry season in Benculuk was February and August, respectively. Rainfall in February reached 350 mm, but it was only 6 mm in August. In Jolondoro, the rainy season's peak occurred earlier in December with a rainfall of 327 mm. In the dry season, there was still a rainfall up to 50 mm (Figure 2). In May, which is the beginning of the dry season, sugarcane is usually started to be harvested, about 11–12 months after planting, and the harvesting lasted in September–October. Planting time for early to middle maturity sugarcane cultivar is in the early to middle of dry season and in the early of rainy season for late maturity cultivar, then the plant is harvested in the following year at the age of a year.

On an annual basis, rainfall in Benculuk was 1,508–2,476 mm, which was sufficient for supporting sugarcane growth and development. A slightly wetter condition occurred in Jolondoro since this place is surrounded by a mountainous area of Ijen and Gunitir (Figure 3). In general, mountainous regions tend to have wetter climates than low elevation areas (Meixner et al. 2016). In 2010, the La Nina phenomenon occurred, and annual rainfall reached 3,673 mm, leading to a wet

**Table 2. Index of Principal Component (PC) of Sea Surface Temperature (SST) (PC1, PC2, PC3) and Southern Oscillation Index (SOI).**

| Year                   | SST       |           |            | SOI    |
|------------------------|-----------|-----------|------------|--------|
|                        | PC1       | PC2       | PC3        |        |
| 1993/1994              | 16.82626  | 40.04939  | 19.30551   | -3.82  |
| 1994/1995              | 17.21809  | 39.99430  | 19.60018   | -6.03  |
| 1995/1996              | 16.10759  | 40.47211  | 18.87006   | 1.7    |
| 1996/1997              | 16.16176  | 40.14755  | 18.95794   | 3.37   |
| 1997/1998              | 19.10259  | 40.49024  | 21.09407   | -18.88 |
| 1998/1999              | 15.73051  | 40.56515  | 18.81568   | 11.63  |
| 1999/2000              | 15.56841  | 40.45697  | 18.55931   | 10.4   |
| 2000/2001              | 16.20759  | 40.61550  | 19.08763   | 11.22  |
| 2001/2002              | 16.51626  | 40.62715  | 18.98819   | 0.23   |
| 2002/2003              | 17.39789  | 40.50409  | 19.73128   | -6.7   |
| 2003/2004              | 16.88305  | 40.59673  | 19.58513   | 0.28   |
| 2004/2005              | 16.95366  | 40.39626  | 19.39064   | -8.02  |
| 2005/2006              | 16.09147  | 40.42285  | 18.88465   | 5.9    |
| 2006/2007              | 17.21348  | 40.44028  | 19.64115   | -5.18  |
| 2007/2008              | 15.60953  | 40.46979  | 18.45614   | 12.87  |
| 2008/2009              | 16.32307  | 40.67086  | 19.02519   | 11.37  |
| Standard deviation     | 1.4845551 | 0.8585137 | 0.24300245 |        |
| Proportion of variance | 0.7346347 | 0.2456820 | 0.01968340 |        |
| Cumulative proportion  | 0.7346347 | 0.9803166 | 1.00000000 |        |

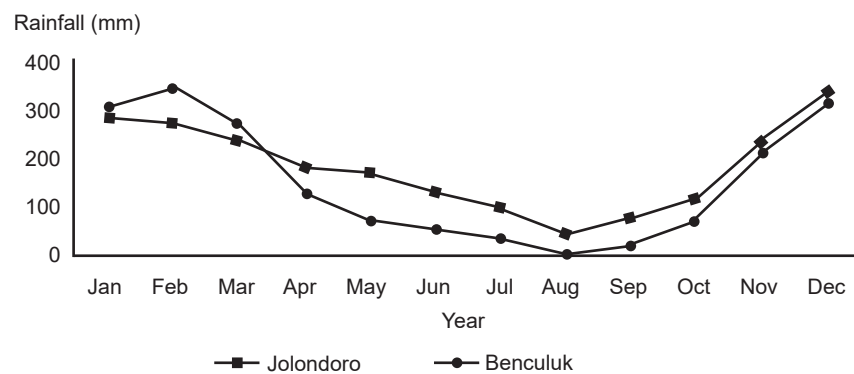


Fig. 2. Average monthly rainfall distribution in Benculuk and Jolondoro, Banyuwangi, East Java, average data of 20 years (1995–2014); data adapted from Irrigation Office of Banyuwangi.

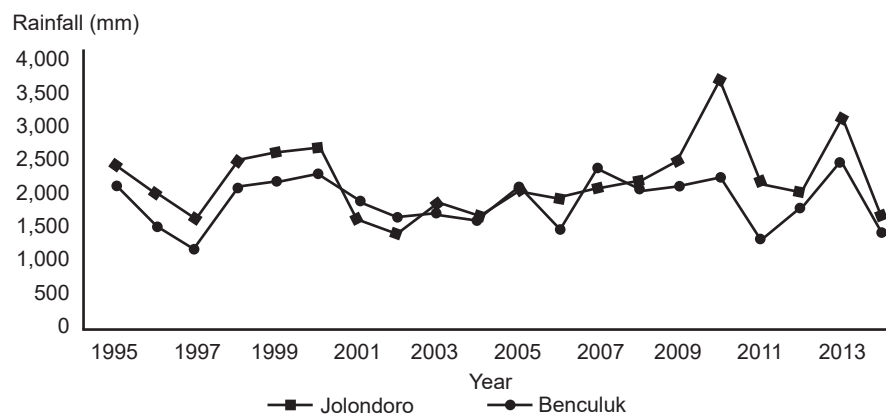


fig. 3. Annual rainfall distribution by year in Benculuk and Jolondoro, Banyuwangi, East Java; data adapted from Banyuwangi Irrigation Office.

climate throughout the year. This is why the land around Jolondoro is primarily used for agriculture, including sugarcane plantation.

### Sugarcane Productivity

Sugarcane productivity was determined by its production divided by planting area that changes over time. From 1995 to 2014, sugarcane productivity in Benculuk fluctuated significantly (Figure 4a). There was a declining trend from 66.9 t ha<sup>-1</sup> to 46.2 t ha<sup>-1</sup> between 1995 and 1999, but there was a consistent increase in productivity from 1999 to 2010. This increase may be linked with the implementation of good agricultural practices (GAP) and superior sugarcane cultivars. Unfortunately, after 2010, sugarcane productivity declined to 52.4 t ha<sup>-1</sup> in 2014.

The first growing season in Jolondoro was 1997. In the first harvest period in 1998, the sugarcane productivity over 70 ha area was 56.2 t ha<sup>-1</sup>. In the subsequent growing season, there was an increase in the plantation area over

time until it was stable in around 440 ha. Since year 2000, sugarcane productivity continued to increase, and it reached a peak in 2006, i.e., 94.5 t ha<sup>-1</sup>. Between 2007 and 2011, sugarcane productivity declined over time. There was a slight increase in 2012, but then it was declined over time (Figure 4b). This decrease may be linked with cultivation techniques, cultivars, and water availability (Pawirosemadi 2011).

### Correlation

The correlation between GCI, rainfall, and sugarcane productivity in Benculuk and Jolondoro can be seen in Table 3.

### Correlation Between SST, SOI, and Rainfall

In Benculuk, there is a negative and significant correlation between SST and rainfall as indicated by a correlation coefficient (*r*) of -0.75 and a determination



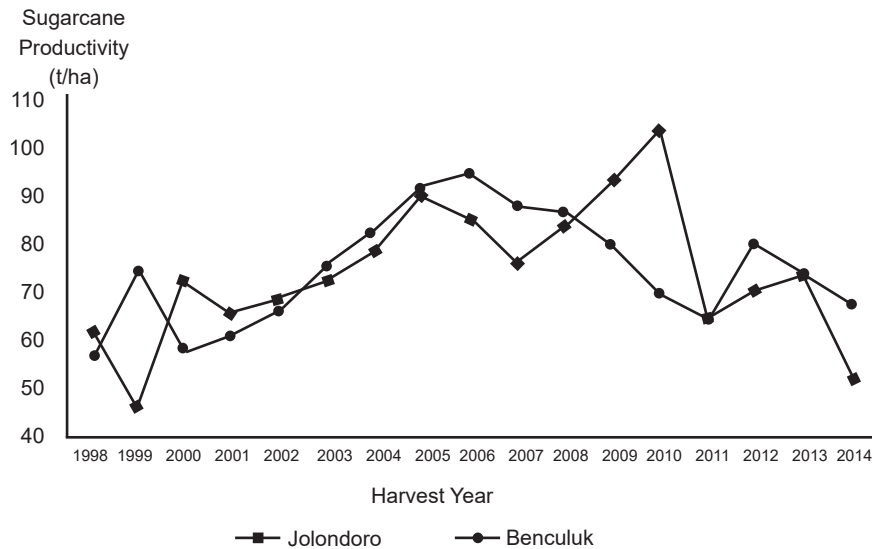


Fig. 4. Sugarcane productivity by year in Benculuk and Jolondoro, Banyuwangi, East Java; data adapted from Research and Development Department of Asembagoes and Semboro sugar mill.

**Table 3. The results of correlation analysis between global climate indices (GCI), rainfall, and sugarcane productivity in Benculuk and Jolondoro, Banyuwangi, East Java.**

| Correlation                        | Location                |                         |
|------------------------------------|-------------------------|-------------------------|
|                                    | Benculuk                | Jolondoro               |
| SST vs rainfall*                   | $y = -352.49x + 7724.1$ | $y = -107.32x + 3443.4$ |
| y = rainfall                       | $r = -0.75$             | $r = -0.50$             |
| x = SST                            | $R^2 = 0.57^*$          | $R^2 = 0.28$            |
| SOI vs rainfall*                   | $y = 38.664x + 1555.1$  | $y = 10.541x + 1567.8$  |
| y = rainfall                       | $r = 0.81$              | $r = 0.50$              |
| x = SOI                            | $R^2 = 0.65^*$          | $R^2 = 0.26$            |
| Rainfall vs sugarcane productivity | $y = -0.0913x + 873.15$ | $y = -0.1672x + 1157.3$ |
| y = sugarcane productivity         | $r = -0.53$             | $r = -0.59$             |
| x = rainfall                       | $R^2 = 0.14$            | $R^2 = 0.34$            |
| SST vs sugarcane productivity      | $y = -2.6027x + 766.37$ | $y = -26.581x + 1222.7$ |
| y = sugarcane productivity         | $r = -0.019$            | $r = -0.205$            |
| x = SST                            | $R^2 = 0.0014$          | $R^2 = 0.038$           |
| SOI vs sugarcane productivity      | $y = -0.49x + 720.38$   | $y = -1.32x + 762.4$    |
| y = sugarcane productivity         | $r = 0.034$             | $r = 0.07$              |
| x = SOI                            | $R^2 = 0.0242$          | $R^2 = 0.048$           |

Note: \* Significant at  $P < 5\%$

SOI = Southern Oscillation Index

SST = Sea Surface Temperature

coefficient ( $R^2$ ) of 0.57. This means that the higher the SST, the lower the rainfall in Benculuk. Since Benculuk located closer to the Indian Ocean, the changes in SST values would have influence on the rainfall. An example, the SST index of 16–17 (Table 2) calculated using the model in Table 3 suggested a rainfall ranging between 1,500 and 2,000 mm. On the contrary, an increase of the SST index up to 20 means a decrease in rainfall below 1,000 mm. There is a similarity of the rainfall pattern between actual and prediction value according to both SST and SOI (Figure 5a and 5b).

There is a positive and strong correlation between SOI and rainfall in Benculuk as indicated by the correlation coefficient ( $r$ ) of 0.81 and the determination coefficient ( $R^2$ ) of 0.65. This means that the higher the SOI, the higher the rainfall in Benculuk. A positive SOI of 0–5 indicates a rainfall of 1,500–2,000 mm, whereas SOI more than 10 means a more than 2,000 mm rainfall. In contrast, a negative SOI index leads to a low rainfall of less than 1,500 mm from October to March.

In Jolondoro, there is a robust correlation between SST and rainfall, with a correlation coefficient ( $r$ ) of

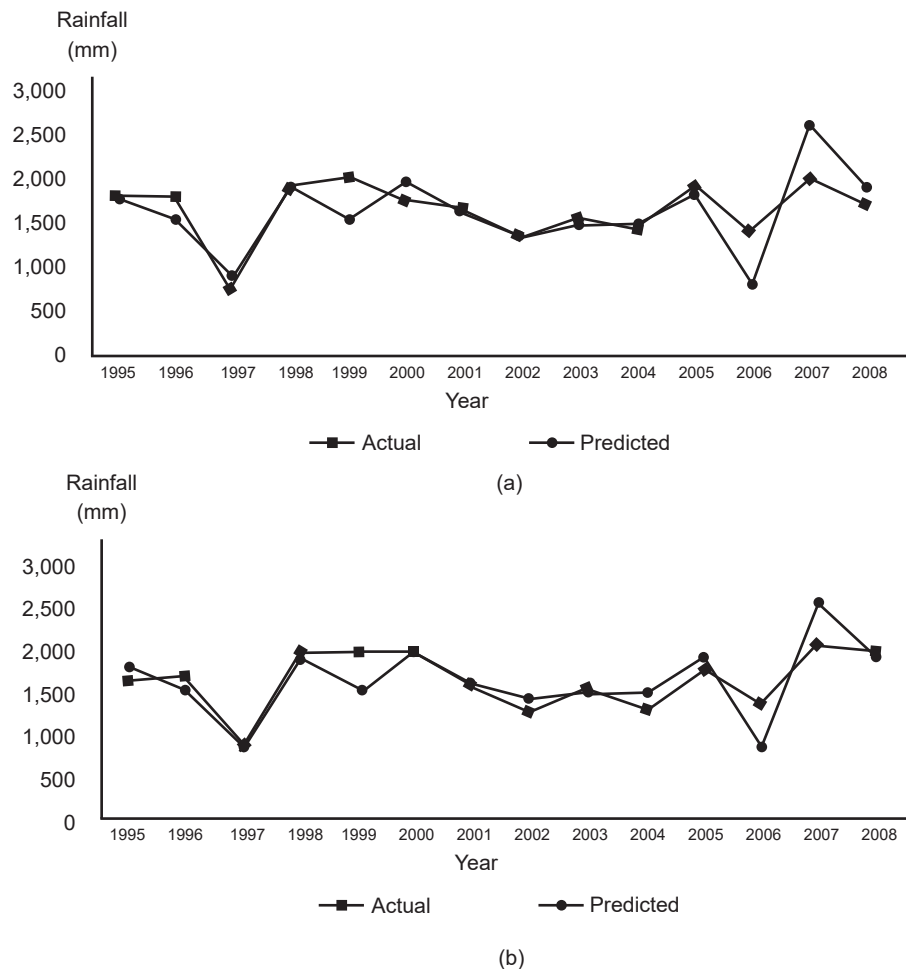


Fig. 5. Actual vs predicted annual rainfall (mm) based on Sea Surface Temperature (SST) data (a) and Southern Oscillation Index (SOI) data (b) in Benculuk, Banyuwangi, East Java.

-0.5, and a determination coefficient ( $R^2$ ) of  $0.28 \approx 0.3$ . The higher the SST, the lower the rainfall in Jolondoro. An SST index of 16–17 means that the rainfall would be at the range of 1,400–2,000 mm during October–March. An SST index of about 20 means a low rainfall, which is less than 1,400 mm. An increase in surface temperature in the Pacific sea leads to the occurrence of El Nino in Indonesia, indicated by a decrease in rainfall since most of the air mass in Indonesia will move to the Pacific sea.

The correlation analysis between SOI and rainfall in Jolondoro resulted in a correlation coefficient ( $r$ ) of 0.5 and a determination coefficient ( $R^2$ ) of 0.25. This means that the SOI has a significant positive influence on rainfall. The higher the SOI, the higher the rainfall in Jolondoro from October to March in the subsequent year. Generally, a positive SOI means a higher rainfall in Indonesia, and vice versa. With a positive pressure difference between Tahiti and Darwin, the air mass will move from the Pacific to Indonesia, which means higher rain potential. A positive SOI of more than 10 means that

there will be rainfall ranging between 1,500–2,000 mm and a negative SOI of more than -10 leads to a lower rainfall than 1,500 mm.

The correlation equation can be used as a model to predict rainfall. A simple validation between actual rainfall and its prediction based on SST and SOI data had been performed. There is a similarity of the pattern between them, although there are deviations in some data points (Figure 6a and 6b).

Nugroho et al. (2013) observed that the SOI and SST index are not the main factor influencing rainfall. There are numerous climatic factors affecting rainfall, such as air humidity, maximum and minimum air temperature, altitude, etc.

### Correlation Between Rainfall and Sugarcane Productivity

In Benculuk, the effect of rainfall on sugarcane productivity is insignificant, with the correlation coefficient ( $r$ ) of -0.53 (Table 3) and the determination

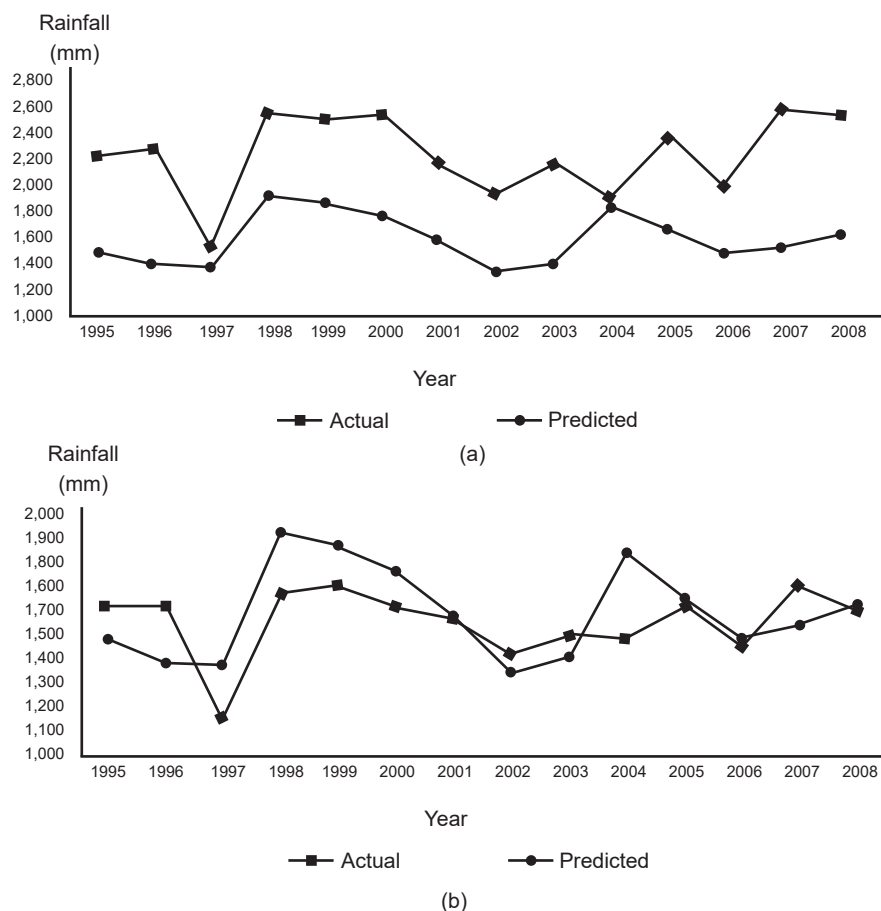


Fig. 6. Actual vs predicted rainfall based on Sea Surface Temperature (SST) data (a) and Southern Oscillation Index (SOI) data (b) in Jolondoro, Banyuwangi, East Java.

coefficient ( $R^2$ ) of 0.14. A rainfall of 1,000–1,500 mm in Benculuk resulted in sugarcane productivity of 80–100 t ha<sup>-1</sup>, and a rainfall above 2,000 mm decreased sugarcane productivity up to 60 t ha<sup>-1</sup>.

In Jolondoro, rainfall is considered as an essential factor affecting sugarcane productivity. There is a negative correlation between rainfall from October to March and sugarcane productivity in Jolondoro, with the correlation coefficient ( $r$ ) of -0.59 and the determination coefficient ( $R^2$ ) of 0.34. A rainfall of 2,000–2,500 mm leads to sugarcane productivity of 70–90 t ha<sup>-1</sup>, and rainfall above 2,500 mm indicates a decrease in sugar productivity below 70 t ha<sup>-1</sup>. Indeed, sugarcane requires a vast amount of water during its growth, especially during the vegetative stage for cane elongation and internodes formation. However, too much rainfall is also not desired as waterlogging may adversely affect sugarcane growth and development (Srivastava and Rai 2012), up to 18–64% reduction in sugarcane yield (Gilbert et al. 2008), depending on the duration of waterlogging, crop growth stage, and cultivars resistance to flooding (Gilbert et al. 2008; Glaz and Lingle 2012).

There is a similarity of the pattern between actual and observed sugarcane productivity based on the correlation equation in Benculuk (Figure 7a) and Jolondoro (Figure 7b), although the prediction result tends to be below the actual sugarcane productivity. This means that the prediction result has a relatively low in accuracy. Several factors affect sugarcane productivity in addition to rainfall, such as crop and soil management, the choice of suitable cultivar, and cultivation management (Pawirosemadi 2011).

### Correlation Between SST, SOI, and Sugarcane Productivity

The correlation between SST and sugarcane productivity in Benculuk is weak and insignificant, with a correlation coefficient ( $r$ ) of -0.019 and a determination coefficient ( $R^2$ ) of 0.0014 (Figure 8a). This implies that SST does not influence sugarcane productivity. Similarly, the correlation between SOI and sugarcane productivity in Benculuk is also insignificant, with a correlation coefficient ( $r$ ) of -0.034 and a determination coefficient



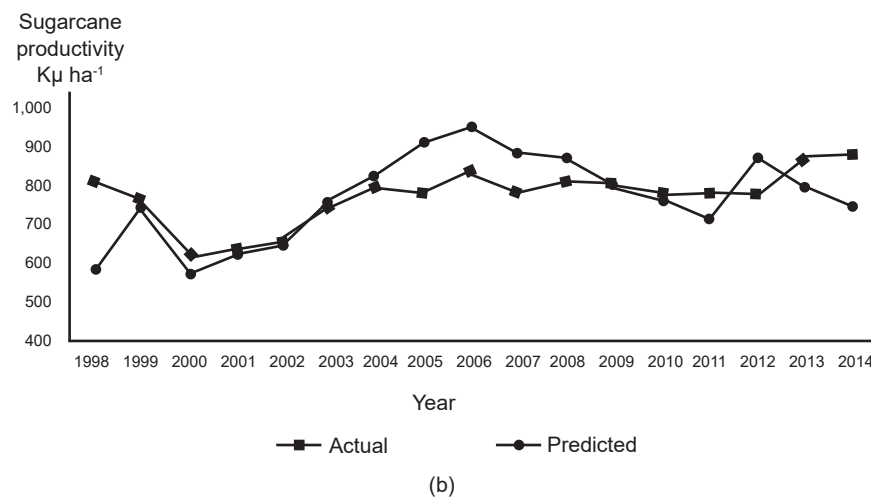
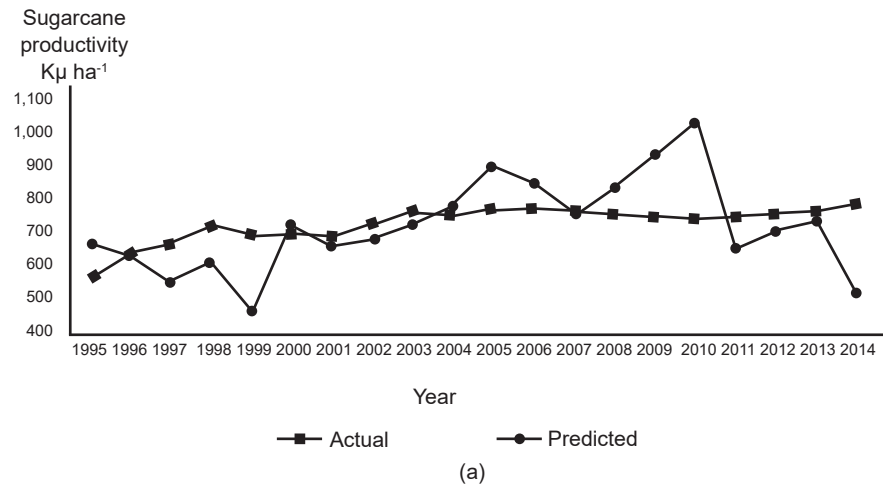


Fig. 7. Actual vs predicted sugarcane productivity based on rainfall data in Benculuk (a) and Jolondoro (b), Banyuwangi, East Java.

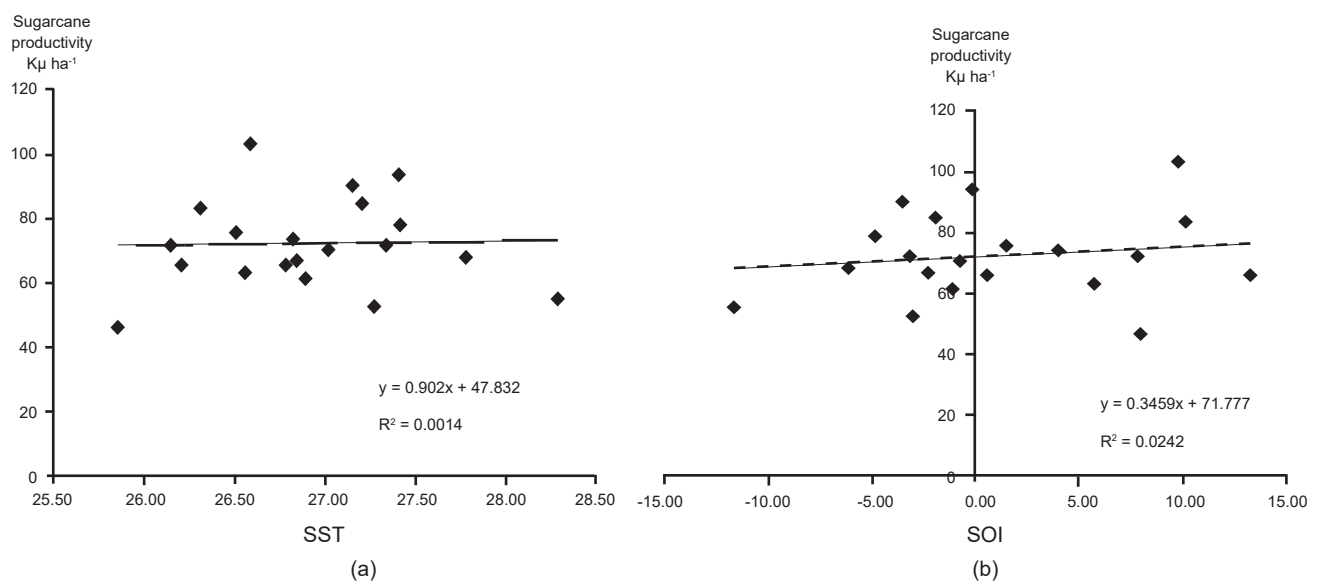


Fig. 8. Correlation between sugarcane productivity and Sea Surface Temperature (SST) (a) and Southern Oscillation Index (SOI) (b) in Benculuk, Banyuwangi, East Java.

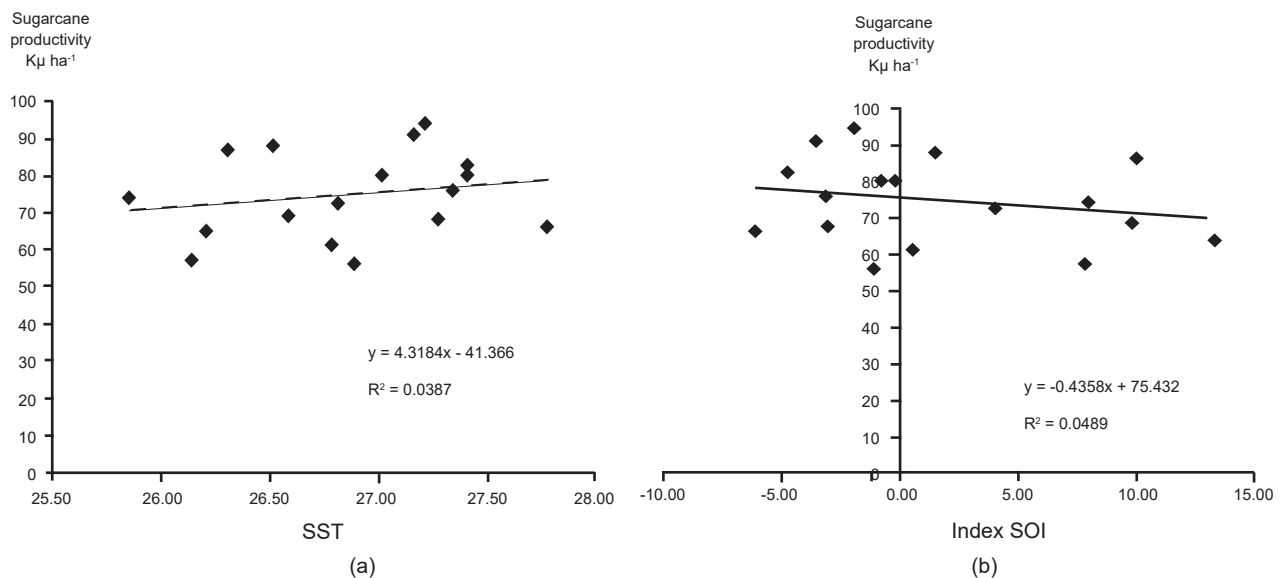


Fig. 9. Correlation between sugarcane productivity and Sea Surface Temperature (SST) (a) and Southern Oscillation Index (SOI) (b) in Jolondoro, Banyuwangi, East Java.

( $R^2$ ) of 0.0242. These low values mean that sugarcane productivity in Benculuk is insignificantly affected by SOI (Figure 8b).

In Jolondoro, the correlation between SST and sugarcane productivity is insignificant, with a correlation coefficient ( $r$ ) of -0.205 and a determination coefficient ( $R^2$ ) of 0.038 (Figure 9a). Meanwhile, the correlation between SOI and sugarcane productivity in Jolondoro is also weak, with a correlation coefficient ( $r$ ) of -0.07 and a determination coefficient ( $R^2$ ) of 0.048 (Figure 9b). This showed that either the SOI or SST index in Jolondoro has a relatively more influence in determining the sugarcane productivity than that in Benculuk.

## CONCLUSION

SOI and SST indices have significant influences on rainfall and can be used to predict rainfall in Benculuk and Jolondoro. Correlation between rainfall, SOI and SST, and sugarcane productivity in Benculuk is insignificant. Rainfall has a significant correlation to sugarcane productivity in Jolondoro, except for SST and SOI. Rainfall ( $y$ ) can be predicted by SST index ( $x$ ) using the equations of  $y = -352.49x + 7724.1$  in Benculuk and  $y = -107.32x + 3443.4$  in Jolondoro. Rainfall ( $y$ ) can also be predicted by SOI index ( $x$ ) using the equations  $y = 38.664x + 1555.1$  in Benculuk and  $y = 10.541x + 1567.8$  in Jolondoro. Sugarcane productivity ( $y$ ) in Jolondoro can be predicted by rainfall ( $x$ ) from October to March using the equation  $y = -0.1672x + 1157.3$ .

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