The Dynamics of Rice Cropping Calendar and Its Relation with the ENSO (El Niño-Southern Oscillation) and IOD (Indian Ocean Dipole) in Monsoon and Equatorial Regions of Indonesia

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Abstract. The relative impacts of the El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) events of Rice Cropping Calendar on Equatorial and Monsoon Region of Indonesia were studied. The spatial distribution of partial correlations between rainfall with the ENSO and IOD over West Sumatera and West Java indicated a significant impact on rainfall anomalies normally along the period of September – November. The ENSO and IOD events, which is known as a monsoon type, had a wider impact in West Java, especially over northern of West Java. On the other hand, there was only a little impact of the ENSO and IOD on rainfall anomalies in the southern-west of West Sumatera. This strength was shown to be associated with the evolution of distinct weather types revealed by Pearson analysis. In these regions, the same impact of the ENSO and IOD on the width of planting area was very weak in the period of December-March whereas that in the period of June-November the impact on West Sumatera reached only 10% moreover, the impact in West Java could reach up to 80%. On the period scales, the ENSO and IOD events had significant impacts to delayed onsets of rice cropping calendar in which they were more intense than previous ones. In general, the magnitude of ENSO-delayed onsets was greater than delays to the IOD. The period-stratified ENSO variability during each of the months from September to November had a significant impact of delayed planting 2 to 4 dekads in West Sumatera and 4 to 6 dekads on West Java. This confirmed that strong ENSO events indeed affected the southern of West Sumatera and northern of West Java. Meanwhile, the period-stratified IOD variability on West Sumatera and West Java had a significant impact of delayed planting 2 to 4 dekads.

1. Introduction

Recently, climate variability and climate change are two phenomena of climate, which became a common concern to have a major impact on life on this earth. Climate variability is more defined as the temporal and spatial variation of the atmospheric system on the average value. Climate variability is the fluctuation of the climate elements that occur in a particular period such as seasonal or annual variations. On the other hand, climate change is a phenomenon of atmospheric composition changes that would gradually increase the observed climate variability on long period [18][21]. Various sectors
will be affected by the existence of that phenomenon. The outline of the impact and adaptation efforts that could be carried out by IPCC [10].

A large fraction of the world’s food is grown as rainfed annual crops in the tropics, where climate variability plays as an important role in determining productivity [20]. Crop growth, development and yield are affected by climatic variability via linear and non-linear responses to weather variables and the exceedance of well-defined crops thresholds, particularly temperature [17] and rainfall in the tropics. The interaction between climate, crops, the land, and water use changes associated with agricultural practices has been largely neglected until recently [1][16]. A large fraction of the land surface in the tropics is used for growing crops where 94% of land in South Asia is used for crop cultivation [4]. Furthermore, FAO studies [5] shows that variability and climate change affect 11% of agricultural land in developing countries that can reduce food production and reduce the GDP to 16%. Meanwhile, the impact of climate variability and change could also decrease the production of food crops (cereals) in Southeast Asia between 2.5% to 7.8% [7].

Climate variability is a climate phenomenon that could be a potential, but on the other hand, it could be a threat to food security. The success of agricultural production, especially food crops, are dependent on climatic conditions optimal for growth and development of food crops. The four components of food security—food availability, food access, food utilisation and food production system stability—are affected by climate [6]. The relative importance of climate change for food security differs between regions [8].

In Indonesia, climate variability has been related to the ENSO in the Pacific Ocean and IOD in the Indian Ocean. Both phenomena can significantly lead to a decrease in rainfall especially in the transitional season when entering the rainy season, resulting in the disruption of the stability of agricultural systems in Indonesia, particularly of food crops [11]. The emergence of a strong El Nino phenomenon as many as seven times for the previous twenty years along with the occurrence of phenomenon of a positive dipole mode/IOD that occurred almost at the same time resulting in considerably serious drought. When a strong El Nino took place, there was a strong positive IOD occurring in the Indian Ocean [19][23].

Variability of the climate had an impact on the production of rice and the second crop in Indonesia, and it was very influential towards the rice planting system and the second crop [14]. For example, El Nino phenomenon and the IOD in the year of 1997/98 shifted the onset of the 1997/1998 rainy season for 2-3 months (60 to 90 days) successively, and this affected the planting period of the following planting season [12]. As a result, rice production was decreased by 6.5%, resulting in the import of rice as much as 3 million tonnes in 1998 [3]. Following this, at the beginning of the 2002/2003 rainy season (November-December 2002), they also shifted the planting pattern in several central areas of rice production in Java. In normal conditions, the realisation of the planting in the rainy season along the north coast of West Java may reach 80%; however, the realisation of planting in 2002/2003 rainy season only reached 45-55%. Due to the climate anomalies, the rice planting of the early rainy season (November – December) to be conducted at the areas close to the water irrigation channels. The area width of destruction of rice plants reached more than 450,000 ha due to the drought, and more than 91,000 ha did not produce any rice. The amount of destruction of food crops in 2003 was much higher than that at the previous ten years [2]. However, the extent to which climate anomalies impact food crops was highly dependent on the level and pace of climate anomalies and the sensitivity level of food crops.

The dynamic fluctuation of rainfall due to the emergence of a climate anomaly results in the shifting of the early rainy season and early dry season. Changes in rainfall patterns and the shifting of the onset lead to changes of the onset, thus causing difficulties to the farmers to determine the exact onset since they are used to applying their own rice cropping calendar. The determination of the rice cropping calendar was the strategy of the cultivation of food crops greatly related to climate anomalies from the fallow period and land preparation, to crop establishment and maintenance, to harvest and storage. In Indonesia, the farmer from generation to generation using different terms in each region have long developed the traditional rice cropping calendar. The term is indigenous knowledge used in planning the agricultural cultivation to determine the onset. Nevertheless, the various local wisdom
cannot be fully made as a reference to set the early planting season due to climate change and the greater difficulty in finding an indicator of a seasonal marker.

This research was conducted as an effort in anticipating the impact of climate variability with the aim to identify areas that are frequently affected by the ENSO and IOD phenomena. This research needs to be carried out in order to know the impact of both phenomena on the rice cropping calendar shift on equatorial and monsoon rainfall type.

2. Methodology
Rainfall datasets were obtained from Indonesian Agroclimate and Hydrology Research Institute, Indonesian Meteorological Climatological and Geophysical Agency, the Department of Public Works and the Department of Agriculture along 17 years from 346 stations rainfall spread across West Java and 113 stations across West Sumatera. Data on planting area width were obtained from the Annual Report of the Department of Agriculture. Moreover, the data of sample areas and existing planting period were obtained from the Report of Rice cropping calendar of Indonesian Agency for Agricultural Research and Development [13]. The index of sea surface temperature at Nino 3.4 (5°N – 5°S, 120°W) was used to find out the amount of impact of ENSO on the occurrence of rainfall, and it may be obtained from the Internet site of http://www.cpc.ncep.noaa.gov. IOD index is expressed in the form of the Dipole Mode Index (DMI), and it may be defined as the difference between the temperature of the sea surface in the western Indian Ocean (50° > 70°E, 10°N - 10°S) and the temperature of the sea surface in the southeast Indian Ocean (90°-110°E, 0°-10°S). The DMI data were obtained from http://www.jamstec.go.jp/frsgc/research/d1/iod.

2.1 Analysis of ENSO, IOD and rainfall anomaly
Analysis of monthly rainfall anomalies on West Sumatera (equatorial rainfall type) and West Java (Monsoon rainfall type) was carried out in each station, and the anomalies towards the value of average rainfall were calculated. Analysis on the impact of the ENSO and IOD anomalies on the dynamics of the rainfalls anomalies as indicators of climate aberration was carried out each month for each period (December-February, March-May, June-August, September-November) in the same year between 1990-2007.

2.2 Correlation analysis of ENSO, IOD with rainfall
Correlation value ranges between -1 and 1 or is written as -1 ≥ r ≤ 1, and the positive or negative sign indicates the direction of its correlation. When the correlation between x and y is negative, the increase in variable x will cause a decrease in y or vice versa. Furthermore, when the correlation between x and y is positive, the increase in the variable x will be followed by the increase in the variable y, or vice versa [22].

A Geographical Information Systems approach was used to delineate the spatial form of the correlation values between the rainfall and the ENSO and IOD. The level of correlation is determined based on strong (99%), moderate (95%) and weak (90%) levels of confidence. Because the number of observations as much as 18 years, based on analysis of "Significance of a correlation coefficient" obtained the strong/high correlation (r ≤ -0.54), moderate/middle (-0.4 ≥ r ≥ -0.53), and weak/low (-0.39 ≥ r ≥ -0.33), whereas unaffected areas have a value (≥ - 0.32).

2.3 Delineation areas affected by ENSO and IOD
Analyses results are presented in the spatial form to facilitate the determination of areas, which are sensitive to climate anomalies. Spatial form of the value of the correlation between ENSO and the IOD with rainfall can produced better picture of which areas were affected by the regional climate. Grid interpolation method was used in displaying the form of spatial correlation between ENSO and the IOD with rainfall.

2.4 Dynamics and the sensitivity of the planting peak
The dynamics of the planting peak shows variability of plant response to a shift in planting time of climatic conditions, while sensitivity cropping calendar shows how many days (dekads/ten-days period) the planting peak shifts. Moreover, the information on the Impact of ENSO and IOD on
planting area width and also the relationship between IOD and ENSO with the dynamics and sensitivity of rice cropping calendar were obtained from overlay between the map of ENSO and IOD impact with the map of rice cropping calendar and planted area data set along 17 years.

3. Results and Discussion
3.1 Rainfall analysis for Indonesian equatorial and monsoon region
West Sumatera is a region with an equatorial rainfall pattern. The pattern indicates a bimodal monthly rainfall distribution with two peaks during the maximum rainy season, showing it in almost right throughout the year. The rainy season reached the peak around April and November or during equinox (a phase when the sun at the closest point to the equator). Meanwhile for West Java, a region with a monsoon rainfall pattern, has a clear difference between the period of the rainy season and dry season with the type of unimodal rainfall (one peak of the rainy season). The rainy season occurs from December to February, and the dry season occurs from June to August. This can be illustrated with the results of the analysis on 346 rainfall stations in West Java and 113 stations in West Sumatera (Figure 1).

![Figure 1. Rainfall pattern in equatorial (a) and monsoon (b) regions.](image)

During the winter season in subtropical areas from December–February, most of West Sumatera regions (equatorial rainfall pattern) showed around 200–300 mm monthly rainfall. Meanwhile, West Java with monsoonal rainfall pattern had relatively higher rainfalls than West Sumatera, i.e. around 300–350 mm/month. It can be suggested that West Java region is highly influenced by west monsoon humid wind stream, which causes a relatively high rainfall during that period. During the transitional period of March–May, both equatorial and monsoonal patterns indicated the rainfall decrease. However, in monsoonal pattern regions, a decrease in rainfall was higher compared to the equatorial region. The difference between these regions reached up to 48% during June – August, when the dry season took place in subtropical regions.

Distribution of rainfall in West Java was relatively more diverse in relation to West Sumatera. Areas along the north coast of West Java had relatively lower rainfalls compared to other regions, and this occurred because (1) a decrease in rainfall was higher towards the period of June - August and (2) an increase in rainfall over the period of September - November was much slower compared to other regions (Figure 2). Similarly, based on statistical analysis of the observational record shows a correlation between onset delay and total rainfall in September–December (when the main rice crop is planted) of -0.94 for West/Central Java indicating that delayed monsoon onset is associated strongly with decreased total rainfall in this period [15].
3.2 Impact of the ENSO and IOD on the dynamics of the rainfalls

During the period of December–February, March–May, and June–August areas with the rainfall anomalies that significantly correlated to the IOD were not found in all parts of West Sumatera. The impact of IOD only occurred during the September-November period in the western and southern parts of West Sumatera (Figure 3a). But the impact of the ENSO effect occurred in eastern part of West Sumatera during June–August period, and it will decrease on September-November. The highest ENSO impact took place in southern part of West Sumatera (Figure 3b).

Areas with rainfall anomalies that significantly correlated to the IOD in the period of June–August were found in all parts of southern West Java in which the impacts became more dominant towards the period of September to November except for some areas of West Java. The impacts of the IOD on the rainfall anomalies decreased dramatically towards the period of December–February, and the least impact appeared in the southern part of West Java during the period of March–May. Unlike the IOD, the impact of ENSO in the period of June–August only occurred in a small number of areas in the northeast and south of West Java, and it became more dominant in the period of September–November with a high correlation level occurred in the northeast of West Java. The impact of ENSO also
disappeared towards the rainy period of December–January, and even in most north-western areas during the transitional period of March–May, the rainfall followed a positive correlation to the increase of IOD. Areas, which were not influenced by IOD and ENSO, covered the western parts of West Java (Figure 4).

**Figure 4.** Level of correlation between rainfall anomalies against IOD anomalies (a) and against ENSO anomalies (b) during September–November period in West Java.

### 3.3 Impact on ENSO and IOD on planting area width.

The impact of ENSO and IOD on the planting area width in the monsoon regions was more obvious than that in the equatorial regions. In the equatorial regions and West Sumatra, the impact of the IOD only occurred in the southern part of West Sumatra in the period of June–August, and the impact became stronger exceeding the ENSO during the period of September–November; however, no more than 20% of the area was affected (Figure 5a). Meanwhile, in the monsoonal regions in West Java, the domination between regional climate (ENSO and IOD) and the impact of monsoon, and/or local climate was mutually alternating between the period of December–March and of June–November. In the period of December–March, the impact of the regional climate was very weak against the planting area width; as a result, the impact of monsoon and/or local climate played an important role in the planting area size in West Java. In the period of June–November, the impact of the regional climate became more dominant compared to the monsoon and/or its local climate. In the period of September–November, both ENSO and IOD gave impact to planting area width as much as 80% of the total area (Figure 5b). Based on the results of the analyses, West Java Province is more vulnerable to the impacts of the dynamics of ENSO and IOD than West Sumatra. This means that the readiness of facilities and infrastructure for the provision of irrigation water should be continuously maintained towards the period of June–November, and it is not recommended for the farmers to carry out planting in the period of June–August because the impact of IOD becomes stronger and the planting area size becomes wider than that of the previous period. The above facts also show that the impact of ENSO and IOD was strong on the areas with the monsoonal rainfall pattern or areas that had a rainfall peak.
The relationships between the anomaly fluctuation of planting area size and the IOD and ENSO are presented in Figure 6. It can be seen that the impact of IOD and ENSO anomalies on the anomaly of planting area size occurred in the period of June–November and May–July where there was an increase of IOD and ENSO occurring at the same time as the decreased of rice planting size area in West Java and West Sumatera respectively.

Figure 5. Planted area of West Sumatera (a) and West Java (b) during September–November period.

Figure 6. The relationship between Planting Area Width fluctuation and climate anomaly fluctuation in West Java (a) and West Sumatera (b).

### 3.4 The relationship between IOD and ENSO and the dynamics and sensitivity of rice cropping calendar.

Generally, in equatorial rainfall pattern as in West Sumatera, the onset was not greatly fluctuated and since the rainfall throughout along the year, cropping area is always available. The impact of ENSO and IOD during June—August and September—November caused the onset peak to occur on the third dekad of May to the first dekad of June. However, in areas which were influenced by both climate anomalies, such as in southern coasts, the onset was delayed 2 or 4 dekads from the first to third dekads of June until third of July to first dekads of August (Figure 7).
Figure 7. The cropping season peak is postponed due to the IOD and ENSO in south coast of West Sumatera.

In the regions with monsoonal rainfall pattern, the impact of ENSO and IOD was much greater than that in the equatorial rainfall regions [11]. Based on the map of existing Rice Cropping Calendar of the Research and Development of Agricultural Department [13], the onset in most parts of West Java started from the third dekads of September to the first dekads of October in which the peak of planting occurred. In the period of December–May, the impact of ENSO was not visible, but it would give a significant impact in the period of June–August, although it only occurred in most of the southeast region of West Java (Runtunuwu and Syahbuddin, 2012), thus resulting in a shift of the planting peak from the third dekads of November to the first dekads of December or around 6 dekads later than the regular onset.

Furthermore, in the period of September–November, the impact of ENSO in the north region of West Java region shifted from west to east. In the northwest region, the relationship between ENSO with rainfall anomalies having a high correlation coefficient (≤ -0.5) did not occur. High correlation occurred in the northern region of West Java where the planting peak occurred in the first and second dekads of November, and this was 4 dekads later than the regular onset. The planting peak of this area was as much as 14% of the onset in northern region of West Java. Whereas the planting peak occurred greatly in northeast region of West Java where the value of the correlation coefficient reached almost 35% of the onset in the region. The planting peak took place from the third dekad of November to the first dekad of December which was 6 dekads later the regular planting (Figure 8).

In contrast to ENSO, the impact of IOD in the Northern West Java only occurred in some areas of northern West Java where the correlation level ranged from low to medium. The shifting of planting peak only occurred in this region when the correlation level was from medium to 6 dekads.

Although the impact of the IOD in the north of West Java shifted the onset, it did not have as much impact as ENSO. In the northwest until northern region of West Java, the onset shifted around 2 to 4 dekads where each onset level was below 20%. Meanwhile, in the northeast region, the shift of onset due to the impact of IOD was visible, i.e. as much as 35 % of the onset occurring from the third dekad of November to the first dekad of December, where the level of correlation was medium (Figure 9).
Figure 8. Relationship between the correlation level and onset during the occurrence of ENSO in the in the northwest (a) north (b) and the northeast (c) region of West Java.

Figure 9. Relationship between the level of correlation and the onset during the occurrence of IOD in the northwest (a), north (b) and the northeast (c) region of West Java.
The impact of ENSO occurred in the southern of West Java, however, there was no significant shift in the onset, and the impact of IOD resulted in the shifting of onset as long as 4 dekads starting from the first to the second dekad of November. Moreover, area in the southwest of West Java was the only region affected by IOD only, where the impact of IOD in this region did not show a shifting of planting pattern, i.e. only 2 dekads later (Figure 10).

![Relationship between the correlation level and the onset during the occurrence of IOD and ENSO in the southwest (a), south (b) and southeast (c) of West Java.](image)

**Figure 10.** Relationship between the correlation level and the onset during the occurrence of IOD and ENSO in the southwest (a), south (b) and southeast (c) of West Java.

It was common that the shifting of the planting peak occurred in areas particularly in the northern part of West Java, which were affected by ENSO. The shifting of planting peak occurred at a low correlation level, i.e. up to 2 dekads later from the second to the third dekad of October, at a medium level, i.e. up to 3 dekads later from the first to the second dekad of November, and at a high correlation level, i.e. 6 dekads later from the third dekad of November to the first dekad of December. Conversely, in the southern area of West Java, the shifting of planting peak mainly affected by IOD was only 2 dekads later (Figure 11). Overall, in the monsoonal rainfall regions, the shifting of planting peak occurred when the occurrence of ENSO dominated the region (Figure 12).
Figure 11. Relationship between the correlation level and the onset on the occurrence of IOD and ENSO in West Java.

Figure 12. Relationship between the occurrence of ENSO and IOD and the onset in West Java.

Peak planting occurred in areas always influenced by ENSO and IOD are generally much slower when compared with areas not affected by the climatic phenomenon. Delays that are often caused by increasing water supply, in general, is limited, especially when there is a strong positive El Nino and IOD. Farmers are waiting for rainfall with moderate to high intensity for three consecutive days. Thus, the occurring time shift can potentially delay the next planting season. Withdrawal time during the dry planting season also observed during field verification. Rice fields that are more distant from irrigation or water resources have a high risk of failure or loss of plant growing season.

Besides, shifting seasons and increased intensity of extreme climate events, especially drought, is also a trigger to the constriction of planting area, and the expansion of planting area that will lose yield, particularly food crops and other seasonal crops. Therefore, climate change and extreme climate events such as ENSO and IOD will threaten national food security and agricultural sustainability in general. As an illustration, a one-time event El Nino (weak to moderate) could reduce the national rice production by 2-3%. A climatic extreme followed by an increase in air temperature will decrease rice production more sharply [9].

In the future, areas with strong indications of ENSO and the IOD that require early treatment to prepare a comprehensive policy and operational strategies for adapting to climate variability, as happened in the northeast region of West Java, must be observed. This is very urgent for sustainable food security. Some strategic efforts may include the adoption of crop varieties that have a high ability to adapt, adjustment of planting time during climate anomalies, and adoption of agricultural practices with shorter growing periods.
4. Conclusion
The different impacts of ENSO and IOD to the decline of rainfall were visible during the dry period (June–August) and the transition period (September–November). The impact was even more clearly observed in areas with monsoonal rainfall type. In West Sumatera, with its equatorial rainfall type, the IOD effect only occurred during September–November period in most of the eastern areas of West Sumatera. The IOD and ENSO effects were clearly increased when entering September–November period in the southern areas of West Sumatera, however, less than 20% of the total area.

The impact of ENSO and IOD to the decline of rainfall was visible in the northern region of West Java. The impact of IOD occurred especially in the southern region of West Java from June to August, and the impact of ENSO on that period only occurred in the north-eastern region of West Java. In the period of September – November, the impact of IOD dominated most of the regions in Southern of West Java. Meanwhile, the impact of ENSO and IOD simultaneously affected almost all areas in West Java except for most parts of Bogor, the northern part of Cianjur, and West Bandung districts.

Areas of rice planting in the west affected by ENSO and IOD reached approximately 80% of the total area in the period September–November, while the increase of ENSO and IOD anomalies caused the decline in planting area width in West Java, and this occurred in the period of June–November. The dynamics of rice cropping calendar due to ENSO and IOD were more visible in monsoonal rainfall type areas, with a slower planting peak, i.e. around 4 to 6 dekads later than the regular planting peak. Though in equatorial rainfall type areas, the onset delay took only 2–4 dekads.

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