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Research Article

Changing rainfall and its adaptation strategies on tea plantation in West Java, Indonesia

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ABSTRACT

Climate change, i.e., changing rainfall refers to drought and excess rainfall, is known to affect the growth and yield of tea production in many regions. However, research on the impact of climate change on tea plantations in Indonesia is still limited. The study aimed to evaluate the impact of changing rainfall on the productivity of tea plantation at Cianjur, West Java. The data was collected from interviews, field data, and company records from April to July 2022. The results showed that changing rainfall of both limited rainfalls during El Nino and excess rainfall during La Nina affected tea production. Annual tea productivity declined during both climatic events. Shortage of water during El Nino primarily reduced crop growth, while excess rainfall during La Nina reduced the capacity of tea pickers and increased labor for crop maintenance. Failure to adapt to the direct and indirect impacts of climate change could contribute to declining tea production in Indonesia. Thus, comprehensive action is needed including capacity building in human resources, water management, and microclimate adaptation such as shading plants and tolerant clones to sustain tea production under climate change events.

Keywords: *Camellia sinensis*; climate change; El Nino; La Nina; sustainable production

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INTRODUCTION

Tea (*Camellia sinensis* (L.) O Kuntze) is an important cash crop in more than 50 countries creating a huge economic impact for farmers in many regions (Chang & Brattlof, 2015). Tea-based beverages have special tastes and aromas that are rich in secondary metabolites (Jin et al., 2018). It is known to have health benefits including the prevention of cancer and heart diseases (Chacko et al., 2010), therefore, it becomes a famous beverage in many countries and especially as a non-alcoholic drink to support halal tourism in some countries like Indonesia.

In Indonesia, tea contributed to foreign exchange US$ 96.3 million in 2020; although, national tea production was declining from 166,867 tons in 2001 to 144,064 tons in 2020, or a decrease of 13.5% (BPS, 2020). The decline in tea production was also reported in other countries such as Sri Lanka and Kenya (Hilal, 2020; Muoki et al., 2020). Global tea industry faces problems of climate change, labor cost, production area, and ecological balance (Prathibhani et al., 2018). According to Manumono and Listiyani (2022) and Nursodik et al. (2021) decreasing tea production in Indonesia is due to the effect of land conversion to other crops and decreasing competitive advantage of tea products. On the other hand, Beringer et al. (2020) using modeling concluded that climate change decreases tea production in Indonesia altogether with Kenya and Sri Lanka while climate change stimulates tea production in China, India, and Vietnam. However, the field data in relation to changing rainfall as the cause of tea decline in Indonesia is rarely reported.

Recently, global tea production is struggling with uncertainty due to the negative impact of climate change (Muoki et al., 2020; Yan et al., 2021; Zhao et al., 2021). Climate change is the impact of global warming; and according to Intergovernmental Panel on Climate Change (IPCC, 2021), the average global temperature in the last decade increases by 1.09 °C from the situation 100 years ago. In tropical regions, tea cultivation exists in the highland where the daily temperature is around 18-25 °C (Zakir, 2018). Tea grows well in the area with an annual rainfall minimum of 1,200 mm, and optimum growth will be achieved at about 2,500-3,000 mm (Hajiboland, 2017), with a maximum of two dry months (monthly rainfall below 100 mm) (Dalimoenthe et al., 2016).

The negative impact of climate change on crops generally through the changing rainfall and strong wind in annual crops (Dulbari et al., 2021; Purwono et al., 2021; Agusta et al., 2022), heavy rainfall and temperature in perennial crops (Santosa et al., 2018; Sianipar, 2021). Gunathilaka and Tularam (2016) noted that the adverse effect of climate change on the tea industries is increasing temperature, drought, and excess rainfall. Anjasari et al. (2020) stated that increasing temperature decreases tea production. Rahman (2022) noted that the profit loss of tea growers was noted in Bangladesh due to climate events.

In Indonesia, like in other western tropical Pacific regions, the most detrimental effect of climate events on crops are extended dry season refers to El Nino and excess rainfall refers to La Nina events (NOAA, 2005). Anjani and Arifin (2020) noted that extended dry spell in tea plantation markedly reduces tea production. Tea production is 16-19% lower in the dry season according to Dalimoenthe et al. (2016), while Rokhmah et al. (2022) estimated the yield reduction up to 53% during drought events. Moreover, Dalimoenthe et al. (2016) stated that young tea plant under severe drought situation is more susceptible to death, especially in the lowlands. Although the impact of climate change is evident in tea plantations (Dalimoenthe et al., 2016; Anjasari et al., 2020), the recent adaptation strategies in tea plantations are rarely reported. The study aimed to evaluate the impact of changing rainfall on the productivity of tea plantation at Cianjur, West Java.

MATERIALS AND METHODS

Research site

The research was carried out at the Gedeh Tea Plantation, Cianjur District, West Java from April to July 2022. Gedeh Tea Plantation is located at an altitude of 700 to 800 m above sea level. The company manages three afdelings: Tanawattee I (Sukamulya Village, Cugenang Subdistrict), Tanawattee II (Padaluyu Village, Sarampad Village, and Cigrass Village, Cugenang Subdistrict), and Tanawattee III (Bunikasih Village, Tegalega Village, and Mekarwangi Village Warung Kondang Subdistrict). The plantation maintains 470.44 ha of productive plant (*tanaman menghasilkan*), i.e., Tanawattee I 175.51 ha, Tanawattee II 144.99 ha, and Tanawattee III 149.94 ha.

The soil type is andosol with a soil structure derived from a young volcanic rock with pH 5.0-6.5. Based on Schmidt Ferguson's climatic classification the plantation has a B climate, i.e., a wet area with an average of 9.3 wet months and 1.7 dry months a year. Annual rainfall for the last 15 years (2006-2020) was 2,309 to 3,892 mm with an average of 3,145 mm (Table 1).

Data collection

The research was carried out through interviews, field checks, and the retrieval of data from the company. An interview was conducted to collect information related to climate change impact and its adaptation strategy using closed questionnaires (Yes/No answer). Further information was collected through open questionnaires. The number of respondents was 13 field officers (all field officers involved).

Field data of 15-year rainfall and tea productivity were obtained from the company. Rainfall data was based on monthly measurement using an ombrometer belonging to the plantation located at Gedeh Plantation.

Data analysis

Climatic classification and its intensity followed published data by Null (2023) at https://ggweather.com. Here, only very strong El Nino and the following events were considered in the discussion section after Athoillah et al. (2017).

Data was performed using multiple linear regression analysis and correlation analysis. Data processing used Microsoft Excel.

Ethics declaration

The person involved in the study had signed consent and agreed that the information collected to be published as a scientific paper. Opinions from person did not represent the company's opinion and there is no obligation for the company to act on their opinion.

RESULTS AND DISCUSSION

Rainfall, El Nino, and La Nina incidents

Rainfall in 2015 was the lowest while 2016 had the highest rainfall in the last 15 years (Table 1), confirmed with statement of Athoillah et al. (2017) as the event of El Nino and La Nina, respectively. According to data ENSO (El Nino Southern Oscillation) which is expressed in the Southern Oscillation Index (SOI), such low rainfall in 2015 is classified as an El Nino event while such high rainfall in 2016 is classified as a La Nina event. Moreover, the NINO index in 2015 reached 2.483 and entered into El-Nino with strong intensity. La-Nina with weak intensity has an impact on increasing rainfall intensity in 2016 (Null, 2023).

Table 1. Annual rainfall, its deviation from the average, and climate classification in Gedeh Plantation.

Year	Annual rainfall (mm)[z]	Deviation from average (mm)	Global climate[y]	
			Classification	Intensity
2006	3,069	-76	El Nino	W
2007	3,145	0	La Nina	S
2008	3,291	146	La Nina	W
2009	2,974	-171	El Nino	M
2010	3,388	243	La Nina	S
2011	3,169	24	La Nina	M
2012	3,047	-98	Normal	-
2013	2,973	-172	Normal	-
2014	3,367	222	El Nino	W
2015	2,309	-836	El Nino	VS
2016	3,892	747	La Nina	W
2017	3,248	103	La Nina	W
2018	3,291	146	El Nino	W
2019	2,884	-261	Normal	-
2020	3,125	-20	La Nina	M
Average	3,145	-	-	

Note: [z] Rainfall data were obtained from Gedeh Plantation; [y] Null (2023), W-weak, M-moderate, S-strong, VS-very strong.

El Nino event is characterized by an anomaly of Sea Surface Temperature (SST) with SST value > +0.5 °C and La Nina event is characterized by SST anomaly values < -0.5 °C (Athoillah et al., 2017). In 2015, the increase in SST around the East and Central Pacific along the equator reached 2.5 °C and was classified as a strong intensity El-Nino. The period of El Nino was from April 2015 to April 2016, while La Nina was from September to December 2016.

During El Nino 2015, total annual rainfall in Gedeh Tea Plantation was markedly low (Table 1, Figure 1). Low monthly rainfall occurred from April to December 2015 and from July to August the rainfall was very low (0-50 mm month^{-1}). Rainfall in July 2015 was absent; this situation was below the average rainfall in July (87 mm month^{-1}) from 2006 to 2020. The rainfall increased a little in August 2015 (5 mm month^{-1}) but was still below the average 15-year rainfall of August (77 mm month^{-1}).

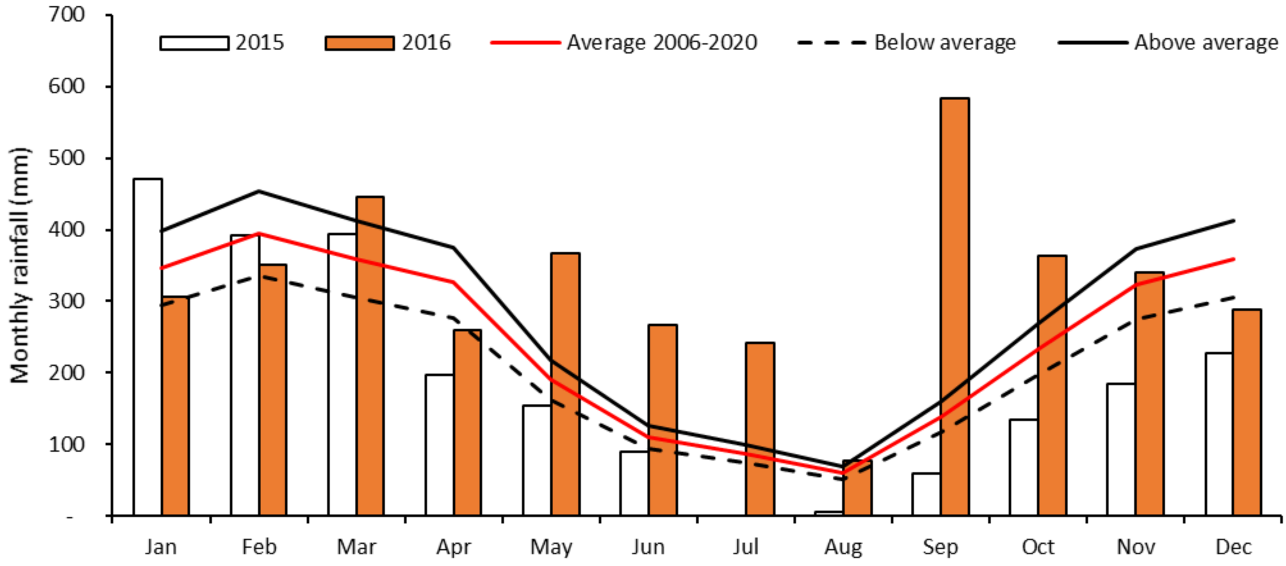


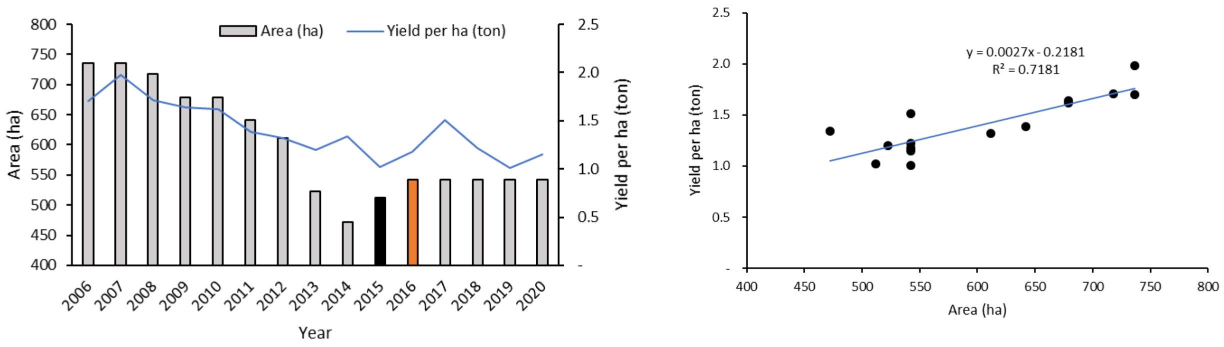
Figure 1. Comparison of monthly precipitation in Gedeh Tea Plantation, Cianjur, West Java during El Nino (2015), La Nina (2016), and the average precipitation of 2006-2020.

During the La Nina event in 2016, annual rainfall was 747 mm higher than the average 15 years (Table 1, Figure 1). Such high rainfall intensity in 2016 contributed to high rainfall in September and October (Figure 1). The rainfall in September (583 mm month^{-1}) was 360% higher than normal rainfall for 15 years of September (160 mm month^{-1}). In practical terminology, the dry season in 2016 became very moist months. In Indonesia, the dry season refers to ASEP (April to September) while the wet season refers to OKMAR (October to March).

Tea production and rainfall pattern

Dry tea production and area for production are presented in Figure 2. Annual productivity varied depending on the year and productive area (Figure 2a). As shown in Figure 3a, the productive area fluctuated but in general, from 2006 to 2020 the area declined. The average land area was 601.3 ha with average productivity was 1.40 ton ha^{-1}. It is interesting to note that tea yield per ha decreased in line with the decreasing area of production (Figure 2a). The correlation test envisages such a phenomenon with R^2=0.7181 (Figure 2b). The cause of such a correlation is still unclear.

Several factors contribute to tea production, i.e., genetic/clone, climate, cultivation technique, and management with rough contributions of about 25%, 15%, 35%, and 25%, respectively (Dalimoenthe, 2013). According to Riani et al. (2022), the production of tea is determined by variety, application of fertilizers and pesticides, plant age, and labor. The high correlation between labor productivity and tea production is also noted by Damanik (2015). Jayasinghe et al. (2019) stated that land slope determines tea production. In the culture technique, Safitri and Junaedi (2018) noted that plant age and pruning have a high contribution to tea productivity. Santosa et al. (2009) stated that high weed infestation has a detrimental effect on tea production. Therefore, it is probable that decreasing land area, production, and productivity as shown in Figure 2, is due to pruning activities, limitation of labor force, and some agronomic conditions. According to Safitri and Junaedi (2018), heavy pruning in tea plantations is conducted regularly every 4-5 years with pruning area ranging from 24 to 28% of the total production area. Moreover, improper pruning might cause plant death. Branching dead at a rate of 10-35% of total branches is common (Safitri & Junaedi, 2018). Factors affecting branch damage mainly arise from improper picking that is affected by work experience, worker age, sharpness of harvesting tools, and supervision.



(a) Production area and productivity (b) Correlation between yield per ha and area

Figure 2. Profile of tea production across the year by area and productivity (a) and correlation between the production area and yield per ha (b) at Gedeh Tea Plantation, Cianjur, West Java.

According to Dalimoenthe et al. (2016), climatic factors such as rainfall distribution greatly affect the production of tea; and the decline of highland tea productivity is lower than that of lowland ones. However, a study conducted by Rahman (2022) in Bangladesh, found that rainfall did not affect organic tea production.

In the present study, yield per ha decreased markedly in 2015 (Figure 2a) which is most likely corresponding to the low rainfall (Table 1). Tea productivity at Gedeh Plantation in 2015 decreased by 24% compared to the previous year. Here, due to the productivity of tea in 2015 and 2016 being below the average within 15 years, it is speculated that changing rainfall has affected the Gedeh Plantation.

The strong El Nino in 2015 caused uneven rainfall and caused drier dry season in particular months (Figure 1). Rainfall ≤60 mm month^{-1} occurred three consecutive months in 2015 (July, August, and September). Figure 3 shows that there was a decrease in the monthly tea productivity by 89 kg ha^{-1} in April as compared to March 2015. The declining tea production in April 2015 was in line with the initiation of the El Nino event (April 2015 to March 2016). Figure 2a shows that productivity gradually increases at the end of 2016 to 2017 corresponding to weak La Nina events as shown in Table 1. It is likely that negative effect of very strong El Nino event in 2015 was compensated by adequate rainfall in subsequent two years, meaning that tea plantation is relatively easy to recover from severe drought. This fact is in line with the finding of Zhang et al. (2020) where tea plant has rapid recovery from long drought stress by three mechanisms, i.e., drought escape, has rapid recovery promoting substances, and has specific metabolites to alter oxidative damages.

Limited water in dry months greatly affects shoot production (Dalimoenthe et. al. 2016). Drought causes stunted tea growth, and every reduction in monthly rainfall by 100 mm reduces monthly tea production by about 30-80 kg ha^{-1} (Supriadi & Rokhmah, 2014). However, data on how many months tea plant able to survive under drought stress is still lacking. Drought stimulates tea plants to produce more *banji* (*pucuk burung*, dormant shoot) than pekoe (*pucuk peko*, active shoot) (Anjarsari et al., 2020). According to Koentjoro et al. (2020), drought stimulates ABA production in tea to coop with limited water through stomatal control. However, frequent stomatal closure might affect the production of photosynthates. It is well known that photosynthesis is essential in plant production and is strongly affected by water availability (Pieters & Souki, 2005). When soil water availability or the soil moisture level represents a decrease in field capacity up to 50%, not only the rate of photosynthesis but also the rate of transpiration in plants decreases and causes stress conditions that greatly affect gas exchange and plant metabolism (Hapsari et al., 2018). As a result, the El Nino episode disturbs tea production due to the limited availability of assimilates.

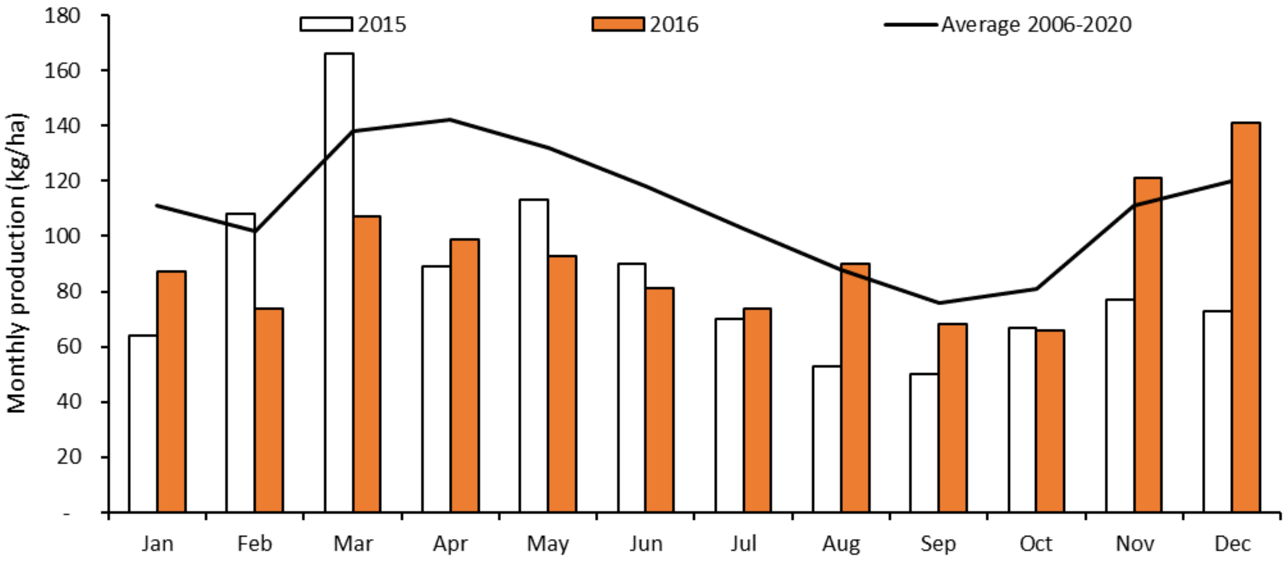


Figure 3. Distribution of monthly tea production during El Nino 2015 and La Nina 2016 incidents in Gedeh Tea Plantation, Cianjur, West Java.

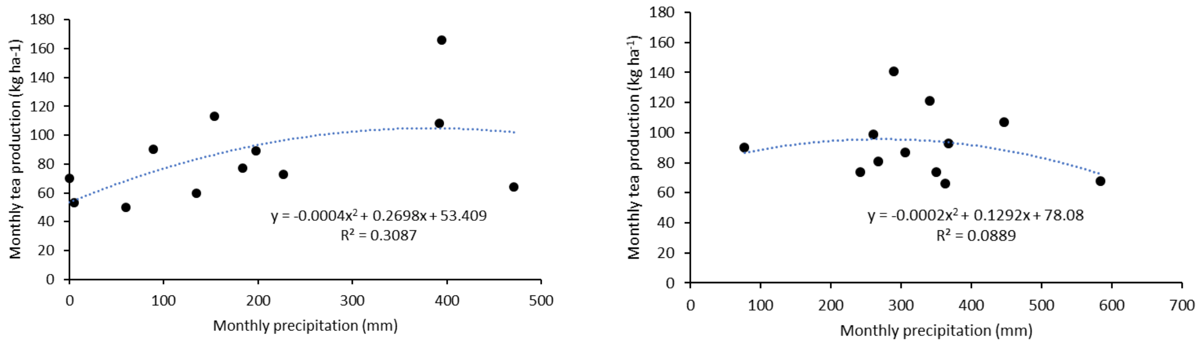
On the other hand, tea plants in 2016 received excess rainfall, especially from March to December (Figure 1). Increasing rainfall during La Nina in 2016 did not have a significant impact on increasing tea productivity in whole months (Figure 3). This means that high rainfall above the normal that occurred from May to November 2016 (Figure 1) was not followed by an increase in tea productivity during the particular month. As shown in Figure 3, monthly tea productivity exceeds the average only for three months, i.e., August, November, and December. It is important to state that average monthly tea productivity during El Nino and La Nina was lower than average, i.e., 85, 92, and 110 kg ha^{-1}, respectively. In general, the land topography of the study site is hilly and excess rainfall easily runs downhill by runoff. Unlike in the report of Dalimoenthe et al. (2016), a flood occurred in some areas of the tea plantation causing a direct impact of La Nina.

Correlation between rainfall and productivity

The correlation between rainfall and tea production per month was weak for both during El Nino and La Nina events (Figure 4). However, correlation evaluation by omitting monthly rainfall value below 300 mm, for each increase in rainfall during El Nino there will be an increase in productivity with a value of R^2=0.6026 (data not shown). On the other hand, when La Nina occurs, an increase in rainfall above 400 mm tended to reduce the monthly tea productivity with a value of R^2=0.1056 (data not shown). These results to some extent are in line with the research of Dalimoenthe et al. (2016), in which the increasing rainfall has a positive linear effect (R^2 = 0.8535) on productivity when rainfall intensity is up to 250 mm per month; and in line with research by Ishak-S et al. (2017) where monthly rainfall > 200 mm or air relative humidity > 85% decreases tea production. Concluding from Figure 1 and Figure 3, drought events in April, May, and June 2015 impacted productivity in June, July, August, and September 2015. It is likely the impact of dry month affects tea production in the second month later. According to Chaeikar et al.

(2019) fifty days after drought treatment, tea production reduces markedly as shown by a smaller number of shoots per plant, lower shoot weight, and smaller leaf size.

In general, it is relatively difficult to explain how the La Nina incident markedly reduced the productivity of the tea plant. Although Dalimoenthe et al. (2016) have studied the impact of climate change in 2006-2014 in tea plantations at different altitudes, the reasons for the decrease in production are not explained apart from explaining the role of water. No explanation was also found in the study of Anjarsari et al. (2020). On the other hand, Rahman (2022) noted the increasing number of new pests in heavy rainfall events in Bangladesh. Many researchers on other crops argue that high rainfall events, namely the La Nina case, will be followed by an increase in pest and disease attacks such as those for cocoa (Santosa et al., 2018). In oil palm, Purwanto and Santosa (2016) stated that high rainfall causes fresh fruit bunch (FFB) to contain high water which easily facilitates the proliferation of oil hydrolyzing microorganisms, and inhibits activities of fruit harvesting and transportation. In the present study, it was observed that there was an indirect effect of high rainfall on the decreasing capacity of plucking, by about 30 to 40%. According to Prastiwi and Lontoh (2019), picker performances are influenced by their skills, work experience, age, climate conditions, plant population, and land topography. In Gedeh Plantation, tea rows mostly were situated on a slope, therefore, high rainfall inhibited the pickers' mobility resulting in a lower capacity for plucking. Figure 3 shows that tea production in November and December 2016 was high; such a situation was supported by normal rainfall of about 300 mm as shown in Figure 1.



(a) El Nino 2015 (b) La Nina 2016

Figure 4. Correlation between monthly tea production and monthly precipitation during El Nino (a) and La Nina (b) incidents in Gedeh Tea Plantation, Cianjur, West Java.

Interestingly, tea productivity in 2017 increased although the total annual rainfall was lower than that in 2016 (Figure 5). Such a carry-over phenomenon was a new perspective in tea, unlike in other years as the productivity of the following year generally decreased by decreasing annual rainfall (data not shown). It is likely that La Nina in 2016 indirectly advantaged tea productivity in 2017.

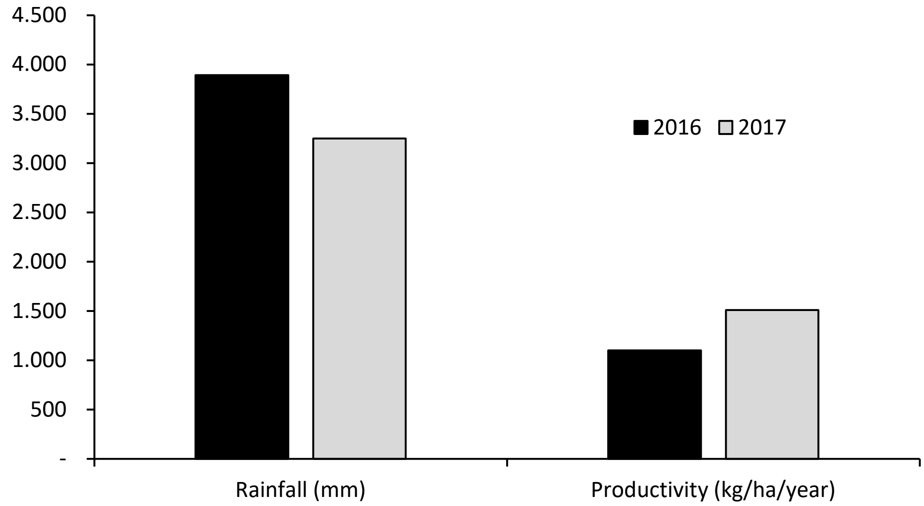


Figure 5. Comparison of annual rainfall and tea productivity during (2016) and after the La Nina event (2017).

Such a carry-over phenomenon is common in oil palm plantations because the availability of water support fruit bunch development and maturity that requires 6 months (Santosa et al., 2011; Hidayat et al., 2013; Barus, 2015); leading to Kartika et al. (2016) developed forecasting model of oil palm production using rainfall. According to Oettli et al. (2018), the effect of a climate event on oil palm production depends on the reproductive stage. Nevertheless, the cause of such a carry-over phenomenon in tea plantations is still unclear. It is speculated that the presence of dead gullies (*rorak*, in Indonesian) constructed in the fields that trap runoff water during heavy rainfall in La Nina might extend soil moisture availability in 2017. It is interesting to study the role of dead gullies concerning the adaptation model of tea plantations in climate change.

Adaptation strategies to climate change

Based on interviews with field workers, most of them did not know the terminology of climate change, the terminology and impacts of El Nino and La Nina, and action programs related to climate change adaptation (Table 2). The proportion of workers who knew about the phenomenon of climate change was low (23.1%) indicating the need for capacity-building activities and outreach programs. On the other side, most respondents had felt the impact of climate change on their activities, for example, the increasing crop severity due to drought and high rainfall, namely 84.6% and 69.2%, respectively.

Table 2. Respondent response at Gedeh Plantation to particular questions related to climate change.

Questions	Response (%)^z	
	Yes	No
Do you know the terminology of climate change	23.1	76.9
Do you know the terminology of El Nino and La Nina	23.1	76.9
Do you know the impact of El Nino and La Nina	23.1	76.9
Do you know adaptation programs for climate change	23.1	76.9
Do you feel a long dry season decreases tea productivity	84.6	15.4
Do you feel heavy rainfall disturbs tea picking	69.2	30.8
Do you feel the long dry season affects pesticide application	61.5	38.5
Do you feel the long rainy season affects pesticide application	61.5	38.5

Note: ^{z} number of respondents = 13 people of officers.

By regulation of *Undang-Undang No 31 of 2009* concerning: meteorology, climatology, and geophysics; the climate change adaptation is briefly defined as efforts that need to be made to anticipate the negative impacts of climate change. According to Fitria and Pratama (2013) El Nino and La Nina events generally occur repeatedly every 4-7 years. Given the different characteristics of El Nino and La Nina, the levels in mitigation and adaptation are: 1) managerial and human resource level, and 2) technical level in the field. Regarding the managerial level, it is necessary to develop an information acquisition system related to the potential for climate anomaly events. This information is then processed to become standard guidelines for tea management activities including developing mitigation strategies and calculating impacts from economic and ecological standpoints. It is also important to increase labor knowledge in the basic terminology, awareness, and specific skill to adapt to climate events, as these issues were still a weakness (Table 2).

According to Gunathilaka and Tularam (2016), the tea industry requires labor-intensive, especially in cultivation and processing. Based on interviews, it is estimated that under La Nina events, the number of workers to maintain productivity is 30-40% higher than in the normal season. Increasing labor activity was noticeable for pickers and crop maintenance. For pickers, high rainfall increased the difficulty in picking tea, especially in slope areas due to the slippery. In the study site, more than 90% of the pickers were women aged > 45 years. Moreover, weeds also grew faster during La Nina leading to more frequent application of weed control than in normal climates. Respondents also noted that during the extended rainy season, pesticides were applied more frequently than under normal climates, i.e., 12 times a year and 4-6 times a year, respectively. The increase in the frequency of spraying fungicides was due to an increase in blister blight disease (*cacar daun,* Indonesian) caused by *Exobadisidium vexans*. According to Fauziah et al. (2018), *E. vexans* spores germinate massively at air humidity above 90% and high rainfall which occurs almost every day.

At the technical level in the field, it is important to maintain stable productivity of tea growth through microclimate manipulation such as the establishment of shading plants especially during El Nino and tolerant tea clones. According to Rokhmah et al. (2022) shading plants maintain soil humidity around tea crop 10% higher and crop temperature 7-9 °C lower than without shading. She recommended several shade plants such as acacia (*Acacia pruinose*, *A. auriculiformis*), *Albizzia falcataria*, calliandra (*Calliandra calothrysus*), *Cassia siamea*, *Erythrina lithosperma*, *Leucaena leucocephala*, and silver oak (*Grevillea robusta*). Planting resistant varieties to drought and extreme rain are also encouraged. Purwaningrum (2006) has identified drought-tolerant clones including GMB 1, GMB 2, GMB 4, GMB 7, GMB 8, GMB 9, GMB 10, GMB 11, and TRI 2025 which have a deep root system. Yuliana et al. (2013) also have identified clones that are resistant to heavy rainfall namely PGL-4, PGL-9, PGL-10, PGL-11, PGL-12, and PGL-16 with production potential over 1 ton of tea per month.

The distribution of rainfall is very important in rain-fed tea production, thus optimizing water resources is a must. Rainwater harvesting in steep land could be done by establishing dead gullies. Small water reservoirs, storage ponds, and lakes could be developed when applicable. In addition, the provision of organic materials such as manure is important to maintain the stability of soil humidity. Rahman (2022) suggested developing organic tea since organic tea production is not been affected by climate change.

Finally, implementing adaptation strategy in tea plantation may vary among sites. In Assam of India, Buruah and Handique (2021) recommended tea growers to harvest rainwater, construct irrigation systems, afforestation, soil mulching and creation of windbreak, use organic manures and pesticides, construct erosion prevention along riversides and embankments to combat climate change. In Kenyan tea, the adaptation strategy should be based ecosystem and biodiversity approach according to Muoki et al. (2020). However in the present study, as depicted in the methodology, the research site had variations in the ecosystem. Since adaptation to climate change requires extra cost of production with degree depending on the ecosystem (Muench et al., 2021). Therefore, further study is needed to develop short and long-term adaptation strategies considering the competitiveness of the tea products to ensure the sustainability of tea business.

CONCLUSIONS

Changing rainfall affected the productivity of tea; both water scarcity during El Nino in 2015 and water excess during La Nina in 2016 reduced tea production. High rainfall affected the plucking capacity of labor due to slower mobility in the field and increase labor requirements due to more frequent weeding and pest control. Nevertheless, La Nina had an indirect positive impact on increasing productivity in the following year. The study envisages the importance of systematic adaptation action such as microclimate management in both El Nino and La Nina events to sustain tea production under changing rainfall in Indonesia.

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