Proceedings of the 5th International Conference on Modern Medicine and Global Health
DOI: 10.54254/2753-8818/2027.39076

# *Evaluating the Contributors and the Environmental Impact of Ecuador Palm Oil Production*

**Angela Yixuan An**

*International School SEK Ecuador, Quito, Ecuador*
*angelaan0912@gmail.com*

***Abstract.*** Oil palm needs warm temperatures and a steady water supply, so climate change may affect its yield. This study examined whether long-term climate conditions were related to oil palm yield in Ecuador between 1975 and 2022, using Brazil as a comparison. Yield data from FAOSTAT were combined with temperature and rainfall data from the CRU TS 4.07 dataset. Annual water deficit and a moisture index were calculated, and multiple linear regression was used to test how temperature, rainfall, and water deficit were associated with yield. Ecuador warmed by about 0.09 °C per decade ($p = 0.038$), while its water deficit decreased by about 17 mm per decade ($p = 0.038$). Yield rose from 6.4 to 16.2 t/ha but varied strongly between years. The climate variables explained only 8.4% of yield variation ($R^2 = 0.084$, $p = 0.272$), and none of them was statistically significant. In Brazil, temperature was linked to yield only until a time trend was added. A simple yield–impact model showed that a 20% fall in yield could raise the environmental impact per kilogram of crude palm oil by 12–20%. The results suggest that, at the national level, management and disease have shaped Ecuadorian yield more than climate has so far.

***Keywords:*** Ecuador's Oil Palm, Climate Change, water deficit, multiple linear regression, life cycle assessment

## 1. Introduction

Climate change is becoming an important challenge for agriculture because changes in temperature and rainfall can affect how crops grow and produce food [1]. Rising temperatures can change plant processes such as photosynthesis, flowering, and water use, while changes in rainfall can affect the amount of water available to plants [2]. Global studies have already found that warming since 1980 has lowered the yields of several major crops, and that each extra degree of warming may reduce yields further [3, 4]. These effects are especially important in tropical regions, where many crops already grow close to their temperature limits. Oil palm (Elaeis guineensis) is a good example because it is a tropical crop that needs suitable temperature and water conditions for productive growth [5, 6]. Like many palms, it belongs to a plant group that evolved in warm and wet rain forest environments [7]. Therefore, changes in temperature and rainfall may affect the conditions needed for stable oil palm production [2].

Oil palm is one of the most important tropical crops because it is the largest source of vegetable oil in the world [8, 9]. It produces more oil per hectare than other major oil crops such as soybean

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2753-8818/2027.39076

and rapeseed, which is one reason why it has spread quickly across the tropics [9, 10]. Its production provides income for farmers and raw materials for food, cosmetics, and biofuel [11]. However, oil palm productivity depends on environmental conditions as well as on farm management. Temperature, rainfall, water availability, soil conditions, nutrients, pests, and diseases can all influence the development of the palm and the production of fruit [12]. Because oil palm is a perennial crop that stays productive for about 25 years, environmental changes can affect production over many years rather than in a single season [5]. For example, drought can reduce yield one to two years later, because flowers and fruit bunches take a long time to develop [13]. For these reasons, climate change may create extra challenges for keeping oil palm production stable.

Temperature is particularly important because oil palm is adapted to warm environments, but higher temperatures do not always improve its growth. Plants have suitable ranges of conditions within which their biological processes work best. When temperatures become too high, photosynthesis and reproductive development can be affected, and water stress can reduce productivity further [6, 12]. Higher temperatures also increase water loss from plants and soil, which makes a lack of rainfall more serious [2, 13]. Oil palm generally grows best with about 2,000 mm or more of rainfall spread evenly through the year, and with a long dry season its yield usually drops [5]. Woittiez et al. [12] found that annual water deficits above 400 mm can cut water-limited yields to less than one-third of their potential. This is relevant to Ecuador, where oil palm is grown in the wet coastal lowlands and in the northern Amazon region [14]. Changes in these climate variables may therefore influence oil palm growth and yield in Ecuador. This means that the link between climate and oil palm productivity may involve several factors acting together rather than temperature alone.

Latin America has become a growing region for oil palm, with Colombia, Ecuador, and Brazil among the countries where the crop is cultivated [14]. Production, harvested area, and yield data can be used to see how productivity has changed over time [8]. Brazil is a useful comparison because its oil palm is grown mainly in the eastern Amazon, under different climate and geographical conditions from Ecuador. Ecuador is also a special case because bud rot, a serious disease caused by Phytophthora palmivora, has damaged many plantations in Latin America [15]. Even so, there is still little Ecuador-specific research on how long-term climate change may be related to oil palm yield. Most existing research on climate and oil palm has focused on Malaysia and Indonesia, while South America has received less attention [2, 6]. Understanding this relationship matters because future changes in temperature and water availability could affect the sustainability and efficiency of oil palm production in the region.

Therefore, this research investigates the relationship between climate conditions and oil palm yield in Ecuador, with particular attention to temperature and water availability. The study uses long-term temperature and rainfall data together with oil palm yield data to examine these relationships [8, 16]. Regression analysis is used to measure how the selected climate variables are associated with yield, while Brazil is included to give a wider South American context. The research also considers the environmental side of changes in productivity from a life cycle assessment (LCA) perspective. Earlier LCA studies of crude palm oil (CPO) have shown that the plantation stage, fertiliser use, and mill efficiency are major sources of environmental impact [17-20]. Since many of these impacts are counted per hectare, a lower yield means that each kilogram of oil carries a larger share of them. By connecting climate, productivity, and environmental impact, this study aims to better understand how climate change may affect the sustainability of palm oil production in tropical South America.

DOI: 10.54254/2753-8818/2027.39076

## 2. Methodology

### 2.1. Data sources

Annual oil palm yield data for Ecuador and Brazil were taken from the FAOSTAT Crops and Livestock Products database (item "oil palm fruit") through the Our World in Data agricultural production collection [8, 21]. Yield is reported as tonnes of fresh fruit bunches per hectare (t/ha). Yield was chosen as the main measure of productivity because, unlike total production, it is not affected by changes in planted area. Monthly mean temperature, maximum temperature, minimum temperature, and precipitation for each country were taken from the CRU TS 4.07 gridded dataset as country averages provided by the World Bank Climate Change Knowledge Portal [16, 22]. The study period was 1975–2022. The study started in 1975 to match the earlier research plan, and it ended in 2022 because that is the last year in the CRU TS 4.07 climate series. Only years with both climate and yield data were used, giving 48 observations for each country.

### 2.2. Climate variables

Four climate variables were prepared for each year. Mean annual temperature (T, °C) was the average of the twelve monthly means, and annual rainfall (R, mm) was the sum of monthly precipitation. Monthly potential evapotranspiration (PET) was estimated with the Hargreaves equation, which only needs temperature data and extraterrestrial radiation [23, 24]:

$$PET = 0.0023 \times Ra \times (T_{mean} + 17.8) \times (T_{max} - T_{min})^{0.5} \quad (1)$$

where Ra is extraterrestrial radiation in mm/day, calculated for a representative latitude of 1.5° S for Ecuador and 10° S for Brazil [23]. The annual water deficit (D, mm) was the sum of monthly shortfalls, that is, the sum of max(0, PET − P) over the twelve months. This approach is similar to the water deficit used in oil palm yield gap studies [12]. The moisture index (M) was calculated as (R − PET) / PET, following the idea of Thornthwaite [25]. Positive values of M mean that rainfall was larger than evaporative demand, and negative values mean that the year was dry.

### 2.3. Regression model

A multiple linear regression model was used to examine the relationship between climate conditions and yield in Ecuador. Yield was the dependent variable because the study focuses on productivity. The full model was:

$$Y_t = \beta_0 + \beta_1 T_t + \beta_2 R_t + \beta_3 D_t + \beta_4 M_t + \varepsilon_t \quad (2)$$

In Equation (2), Yt is oil palm yield (t/ha) in year t; Tt is mean annual temperature (°C); Rt is annual rainfall (mm); Dt is annual water deficit (mm); and Mt is the moisture index. β0 is the intercept, β1 to β4 are the coefficients to be estimated, and εt is the error term, which covers variation in yield that the model does not explain. A positive coefficient means that a higher value of the variable was linked with higher yield when the other variables were held constant, and a

DOI: 10.54254/2753-8818/2027.39076

negative coefficient means the opposite. These variables were chosen because temperature and water availability affect oil palm growth, flowering, fruit development, and production [2, 12, 13].

Because R, D, and M all describe water conditions, multicollinearity was checked with the variance inflation factor (VIF). A VIF above 10 was taken as a sign that a variable overlapped too much with the others and should be removed [26]. A second model (Model 2) added a linear time trend (t = year − 1975) to account for slow changes in technology, planting material, and farm management that are not related to climate. Because yearly data can be autocorrelated, the Durbin–Watson statistic was reported and Newey–West standard errors with a lag of two years were calculated as a robustness check [27]. Results were treated as statistically significant at $p < 0.05$. Long-term trends in each variable were tested with simple linear regression against year. All calculations were carried out in Python (NumPy, pandas, and SciPy). The regression identifies statistical associations only and does not by itself prove causation.

### 2.4. Comparison with Brazil

The same data, variables, and models were applied to Brazil. Comparing the two countries helps to show whether differences in climate trends are matched by differences in yield trends. Published research was used to help interpret the results rather than to decide them in advance. Since national climate averages cover large areas, both countries were interpreted with care, and this point is discussed as a limitation.

### 2.5. Yield–impact sensitivity (LCA perspective)

No new field inventory was collected for this study, so a full LCA was not carried out. Instead, a simple parameter model was built to show how changes in yield would change the environmental footprint of CPO. The approach follows a cradle-to-gate system boundary (nursery, plantation, harvesting, transport, and milling) and uses 1 kg of CPO as the functional unit, as in earlier studies [19, 20]. The impact per kilogram of CPO was split into two parts: a share f that is caused by activities on each hectare (such as fertiliser, field emissions, and machinery) and a share (1 − f) that depends on the amount of fruit processed at the mill. The relative impact was then:

$$I/I_0 = [f \times (Y_0/Y) + (1 - f)] \times (OER_0/OER) \quad (3)$$

where Y0 is the baseline yield, Y is the new yield, and OER is the oil extraction rate. The baseline yield was the Ecuadorian average for 2018–2022 (13.77 t/ha), and the baseline OER was set at 20%, close to the starting value used by Zen et al. [20]. Because f differs between plantations and impact categories, three values were tested: 0.50, 0.65, and 0.80. These values reflect the finding that the plantation stage is usually the largest source of impact in palm oil LCAs [17-19]. Land occupation was calculated directly as 1 / (Y × OER), in hectares per tonne of CPO. All values in Section 3.5 are calculations made in this study, while the values quoted from Zen et al. [20] are published results used for comparison.

DOI: 10.54254/2753-8818/2027.39076

## 3. Results

### 3.1. Yield trends in Ecuador and Brazil

Figure 1 shows oil palm yield in Ecuador and Brazil from 1975 to 2022. Ecuador's yield increased from 6.41 t/ha in 1975 to 16.24 t/ha in 2022. The linear trend was +0.70 t/ha per decade ($R^2 = 0.162$, $p = 0.005$). However, Ecuador's yield changed strongly from year to year. Its standard deviation was 2.44 t/ha and its coefficient of variation was 20.3%. The highest yield was 16.31 t/ha in 1989, and the largest one-year fall was 32.4%, from 1998 to 1999. Brazil's yield rose from 10.61 t/ha to 14.71 t/ha, with a similar trend of +0.70 t/ha per decade but a much better fit ($R^2 = 0.338$, $p < 0.001$). Brazil's yield was steadier, with a coefficient of variation of 15.4%. Its lowest value was 7.59 t/ha in 1991. Ecuador's yield was higher than Brazil's in most years before 2002, the two countries were similar between 2002 and 2016, and Ecuador moved ahead again after 2020.

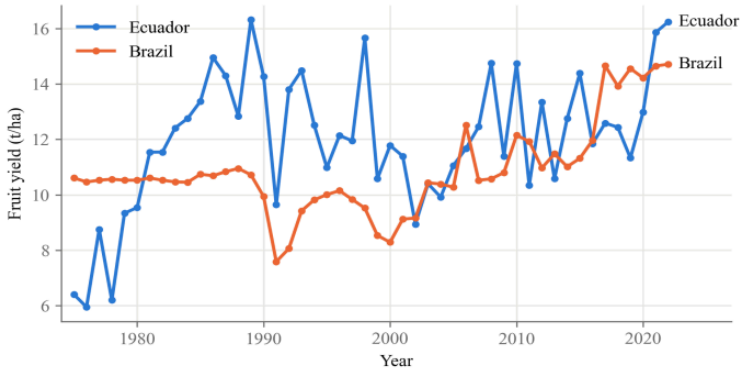



Figure 1. Oil palm fruit yield in Ecuador and Brazil, 1975–2022. Data: [8]

Table 1. Descriptive statistics, 1975–2022 (n = 48 years per country)

| Country | Variable | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Ecuador | Yield (t/ha) | 11.99 | 2.44 | 5.95 | 16.31 |
| Ecuador | Temperature (°C) | 21.36 | 0.41 | 20.33 | 22.28 |
| Ecuador | Rainfall (mm) | 2066 | 396 | 1418 | 3145 |
| Ecuador | Water deficit (mm) | 218 | 80 | 42 | 418 |
| Ecuador | Moisture index | 0.24 | 0.23 | -0.15 | 0.86 |
| Brazil | Yield (t/ha) | 10.87 | 1.68 | 7.59 | 14.71 |
| Brazil | Temperature (°C) | 25.25 | 0.39 | 24.43 | 25.97 |
| Brazil | Rainfall (mm) | 1780 | 88 | 1591 | 1974 |
| Brazil | Water deficit (mm) | 308 | 43 | 228 | 417 |
| Brazil | Moisture index | 0.04 | 0.06 | -0.09 | 0.18 |

*Note: Climate values are national averages from CRU TS 4.07. Water deficit and moisture index were calculated in this study.*

### 3.2. Climate trends in Ecuador

No new field inventory was collected for this study, so a full LCA was not carried out.

DOI: 10.54254/2753-8818/2027.39076

Figure 2 shows the temperature and water deficit trends in Ecuador. Mean annual temperature increased by 0.09 °C per decade (p = 0.038). The average temperature was 21.26 °C in 1975–1984 and 21.65 °C in 2013–2022, an increase of about 0.4 °C. The national average is lower than the temperature in the lowland growing areas because it also includes the cold Andean highlands. Annual rainfall showed a small upward trend of 46 mm per decade, but it was not significant (p = 0.271). The annual water deficit fell by 17.3 mm per decade (p = 0.038), from an average of 232 mm in 1975–1984 to 177 mm in 2013–2022. The moisture index did not show a significant trend (p = 0.301). In every year the Ecuadorian water deficit stayed at or below 418 mm, and its mean of 218 mm was well under the 400 mm level that Woittiez et al. [12] linked to large yield losses. In short, Ecuador became slightly warmer but not drier at the national scale.

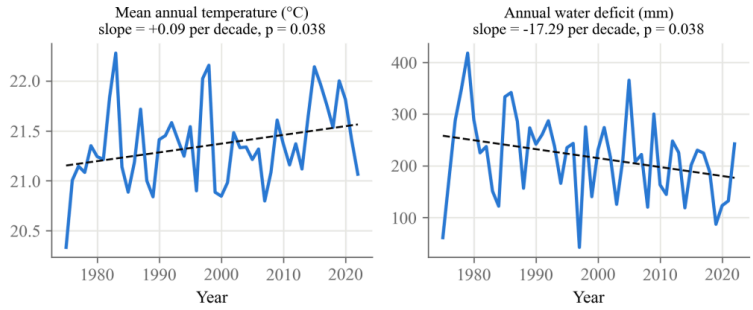



Figure 2. Mean annual temperature (left) and annual water deficit (right) in Ecuador, 1975–2022

Dashed lines show linear trends. Data: [16, 22].

### 3.3. Relationship between climate and yield in Ecuador

Figures 3 to 5 show the simple relationships between each climate variable and yield in Ecuador. Temperature had a weak positive correlation with yield (r = 0.26, $R^2$ = 0.070), but it was not significant at the 5% level (p = 0.070). Rainfall (r = 0.19, p = 0.205) and the moisture index (r = 0.17, p = 0.241) also had weak positive links with yield that were not significant. Water deficit had almost no relationship with yield (r = −0.01, p = 0.958). In all three figures the points are widely scattered, which means that years with similar climate often had very different yields.

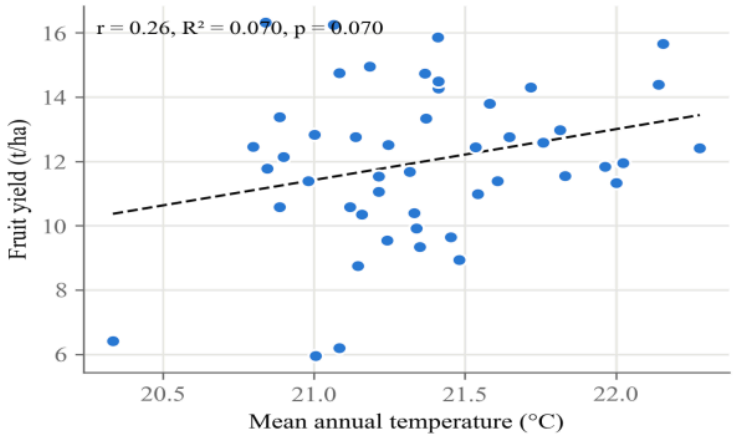



Figure 3. Mean annual temperature and oil palm yield in Ecuador, 1975–2022. Dashed line: least-squares fit

DOI: 10.54254/2753-8818/2027.39076

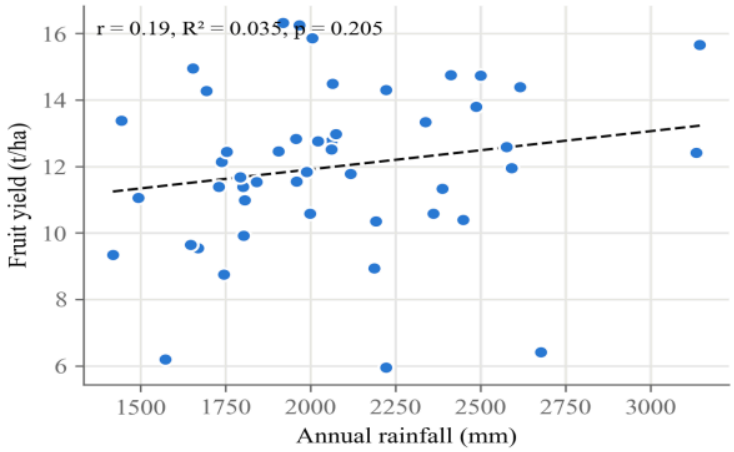



Figure 4. Annual rainfall and oil palm yield in Ecuador, 1975–2022. Dashed line: least-squares fit

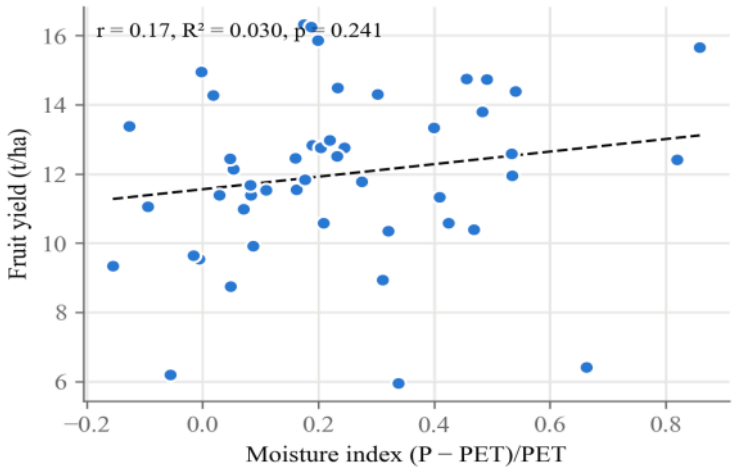



Figure 5. Moisture index and oil palm yield in Ecuador, 1975–2022. Dashed line: least-squares fit

The full model with all four variables had very strong multicollinearity. The VIF was 1,125 for rainfall and 1,082 for the moisture index, because the moisture index is calculated directly from rainfall and PET (their correlation was 0.998). The moisture index was therefore removed, and the final VIF values for temperature, rainfall, and water deficit were 1.24, 1.82, and 1.52. Table 2 shows the regression results. In Model 1, temperature, rainfall, and water deficit together explained only 8.4% of the variation in yield ($R^2 = 0.084$, adjusted $R^2 = 0.022$), and the model as a whole was not significant ($F(3, 44) = 1.35$, $p = 0.272$). None of the three coefficients was significant. The temperature coefficient was positive ($\beta 1 = 1.25$ t/ha per °C, $p = 0.201$), but its standard error was almost as large as the coefficient itself.

Table 2. Multiple linear regression results for oil palm yield (t/ha), 1975–2022

| Variable | Ecuador Model 1 | Ecuador Model 2 | Brazil Model 1 | Brazil Model 2 |
|---|---|---|---|---|
| Intercept | -17.4338 (19.5278) p = 0.377 | -2.7546 (18.8273) p = 0.884 | -36.5659* (18.1374) p = 0.050 | 54.0506 (35.7006) p = 0.137 |
| Temperature T (°C) | 1.2507 (0.9630) p = 0.201 | 0.3848 (0.9433) p = 0.685 | 1.7584* (0.7704) p = 0.027 | -1.6232 (1.3752) p = 0.244 |
| Rainfall R (mm) | 0.0010 (0.0012) p = 0.418 | 0.0015 (0.0011) p = 0.195 | 0.0007 (0.0035) p = 0.833 | -0.0030 (0.0035) p = 0.395 |

DOI: 10.54254/2753-8818/2027.39076

Table 2. (continued)

| | | | | |
|---|---|---|---|---|
| Water deficit D (mm) | 0.0031 (0.0054) p = 0.564 | 0.0080 (0.0053) p = 0.139 | 0.0055 (0.0091) p = 0.547 | 0.0024 (0.0085) p = 0.778 |
| Time trend t (years) | – | 0.0737** (0.0258) p = 0.007 | – | 0.1034** (0.0359) p = 0.006 |
| $R^2$ / adj. $R^2$ | 0.084 / 0.022 | 0.230 / 0.158 | 0.250 / 0.199 | 0.371 / 0.313 |
| F (p) | 1.35 (0.272) | 3.21 (0.022) | 4.90 (0.005) | 6.35 (0.000) |
| Durbin–Watson | 0.84 | 0.88 | 0.51 | 0.49 |
| n | 48 | 48 | 48 | 48 |

*Note: Coefficients with standard errors in brackets. * $p < 0.05$; ** $p < 0.01$. The moisture indexwas removed because of multicollinearity (VIF > 1,000).*

When the time trend was added (Model 2), the explained variation rose to 23.0% ($R^2 = 0.230$, adjusted $R^2 = 0.158$), and the model became significant ($F(4, 43) = 3.21$, $p = 0.022$). The time trend was the only significant variable ($\beta = 0.074$ t/ha per year, $p = 0.007$). The temperature coefficient became much smaller ($\beta1 = 0.38$, $p = 0.685$), which suggests that part of the earlier temperature effect simply reflected the fact that both temperature and yield increased over time. The Durbin–Watson values (0.84–0.88) showed positive autocorrelation in the residuals. With Newey–West standard errors, the time trend stayed significant ($p = 0.030$), and the water deficit coefficient became just significant ($\beta3 = 0.008$ t/ha per mm, $p = 0.046$), while rainfall was close to significant ($p = 0.052$). The positive sign for water deficit is the opposite of what was expected, and it is discussed in Section 4.

## 3.4. Comparison with Brazil

Brazil warmed much faster than Ecuador. Its mean temperature increased by 0.25 °C per decade ($R^2 = 0.807$, $p < 0.001$), from 24.76 °C in 1975–1984 to 25.73 °C in 2013–2022. Unlike Ecuador, Brazil also became drier. Its water deficit rose by 16.9 mm per decade ($p < 0.001$), from 281 mm to 348 mm, and its moisture index fell ($p = 0.020$). In Brazil's Model 1, the climate variables explained 25.0% of yield variation ($F(3, 44) = 4.90$, $p = 0.005$), and temperature had a significant positive coefficient ($\beta1 = 1.76$ t/ha per °C, $p = 0.027$). However, after the time trend was added, the temperature coefficient became negative and was no longer significant ($\beta1 = -1.62$, $p = 0.244$), while the trend was significant ($p = 0.006$). This means that the link between warming and yield in Brazil was mostly a shared upward trend and not clear evidence that higher temperature raised yield. Overall, the two countries had the same long-term yield gain of about 0.7 t/ha per decade, even though their climate trends were quite different.

## 3.5. Yield–impact sensitivity

Table 3. Change in environmental impact per kg CPO under different yield changes (baseline 13.77 t/ha, OER = 20%)

| Yield scenario | Yield (t/ha) | f = 0.50 | f = 0.65 | f = 0.80 | Land use (ha/t CPO) |
|---|---|---|---|---|---|
| +10% (higher yield) | 15.15 | -4.5% | -5.9% | -7.3% | 0.330 |
| −10% | 12.39 | +5.6% | +7.2% | +8.9% | 0.403 |
| −17.7% (one SD of Ecuador yield) | 11.33 | +10.8% | +14.0% | +17.2% | 0.441 |
| −20% | 11.02 | +12.5% | +16.3% | +20.0% | 0.454 |
| −32.4% (largest observed annual fall, 1999) | 9.31 | +24.0% | +31.2% | +38.3% | 0.537 |

*Note: f is the share of impact that depends on the area farmed. Baseline land use is 0.363 ha per tonne of CPO. All values were calculated in this study.*

DOI: 10.54254/2753-8818/2027.39076

Table 3 and Figure 6 show the results of the yield–impact model. At the baseline yield of 13.77 t/ha and an OER of 20%, one tonne of CPO needed 0.363 ha of plantation land. A 10% fall in yield increased the impact per kilogram of CPO by 5.6–8.9%, depending on f. A fall equal to one standard deviation of Ecuador's yield (17.7%) increased the impact by 10.8–17.2%, and a 20% fall increased it by 12.5–20.0%. If yield dropped as sharply as it did in 1999 (−32.4%), the impact per kilogram would rise by 24.0–38.3%, and land use would increase to 0.537 ha per tonne. The relationship is not linear, so each additional loss in yield causes a larger increase in the footprint than the previous one. At Ecuador's long-term average yield (11.99 t/ha), land use was 0.417 ha per tonne, which is 15% more than at the 2018–2022 baseline. In 2022, Ecuador's yield of 16.24 t/ha corresponded to 0.308 ha per tonne, compared with 0.347 ha per tonne for Brazil's 2018–2022 average yield.

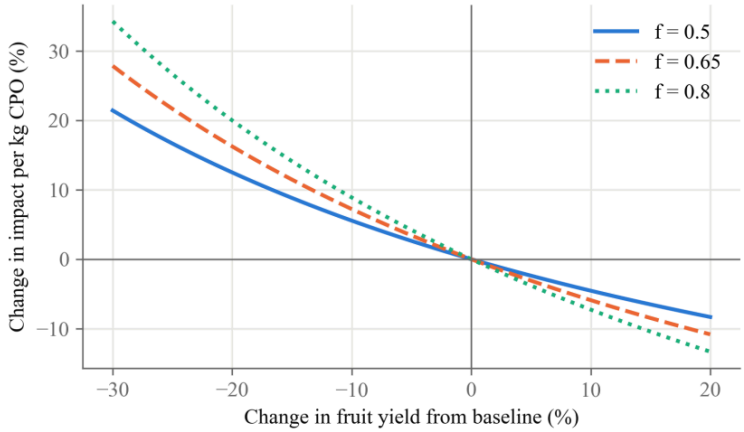



Figure 6. Modelled change in environmental impact per kg CPO for a given change in fruit yield, for three values of the area-based impact share f

The model was also used to check the effect of mill efficiency. Increasing the OER from 20% to 21% and 22% lowered the impact per kilogram by 4.8% and 9.1%. Zen et al. [20] reported reductions of about 3% and 8% for the same OER values in their full LCA. The two sets of results are close, which suggests that the simple model gives reasonable estimates. As an example of how climate can be linked to impact, the Model 2 coefficient for water deficit (0.008 t/ha per mm) means that 100 mm more deficit would change yield by about +0.8 t/ha (+5.8%) and the footprint by about −3.6% when f = 0.65. However, this coefficient was only significant with Newey–West standard errors, so it should be treated as an illustration and not as a firm prediction.

## 4. Discussion and conclusion

### 4.1. Climate and yield

The main finding of this study is that, at the national level, the selected climate variables explained only a small part of the changes in Ecuadorian oil palm yield between 1975 and 2022. Temperature increased slowly and the water deficit decreased, but neither change had a clear and significant link with yield in the main model. This does not mean that climate is unimportant for oil palm. Instead, it suggests that other factors had a stronger effect on national yield over this period. The steady time trend, which was significant in both countries, probably reflects improvements in planting material, fertiliser use, and plantation management [12]. The large ups and downs in Ecuador's yield are also consistent with disease outbreaks such as bud rot, which can destroy large areas of plantations

DOI: 10.54254/2753-8818/2027.39076

within a few years [15]. Changes in how harvested area and production are recorded may add further noise to the national data.

The positive sign for water deficit in Model 2 was surprising, because drought is usually expected to reduce yield [12, 13]. One possible explanation is that Ecuador's oil palm areas are very wet and often cloudy. In such places, a slightly drier year may bring more sunshine, and more light can increase photosynthesis as long as water is not seriously limited [5]. Ecuador's mean water deficit of 218 mm was also far below the 400 mm level at which Woittiez et al. [12] found large losses, so water shortage may not yet be a main limit at the national scale. The very wet El Niño year of 1997–1998, followed by the large yield fall in 1999, also shows that too much water and flooding can be a problem. Even so, the deficit effect was weak and depended on the choice of standard errors, so it should be tested again with plantation-level data.

The comparison with Brazil gives a useful warning about time series data. In Brazil, temperature first appeared to have a strong positive effect on yield, but this effect disappeared after the time trend was added. This happened because both temperature and yield rose over time for different reasons. Studies that link climate and yield without controlling for trends may therefore give misleading results [3]. Brazil also warmed nearly three times faster than Ecuador and became drier, with a mean deficit of 308 mm over the study period. If this trend continues, some Brazilian growing areas may move closer to the deficit levels that are known to reduce yield [12]. Paterson et al. [6] predicted similar risks for Malaysia and Indonesia, so the risk is not limited to one region.

### 4.2. Environmental implications

The yield–impact model shows why productivity matters for the sustainability of palm oil. Many environmental impacts of CPO, such as fertiliser emissions and land occupation, are produced on each hectare of plantation [18, 19]. When yield falls, the same impacts are shared by less oil, so the footprint per kilogram rises. According to the model, a 20% yield loss would increase the impact per kilogram of CPO by roughly 12–20%. It would also mean that about 25% more land is needed to produce the same amount of oil, which could add pressure to clear new land [9, 14]. Improving mill efficiency can partly balance these losses, as shown by the OER results and by Zen et al. [20]. Later processing steps, such as turning palm oil into fatty acids, add further impacts beyond the mill gate [28]. For this reason, keeping yields stable under a changing climate is useful not only for farmers but also for lowering the environmental cost of palm oil.

### 4.3. Conclusions, limitations, and future research

This study examined whether climate conditions were related to oil palm yield in Ecuador from 1975 to 2022, with Brazil as a comparison. Ecuador became slightly warmer (+0.09 °C per decade) while its water deficit decreased. Its yield more than doubled over the study period but varied widely from year to year. Temperature, rainfall, and water deficit together explained only 8.4% of the variation in Ecuadorian yield, and none of them was significant in the main model. A time trend explained more of the variation, which suggests that management, technology, and disease played a larger role than climate at the national level. In Brazil, the apparent effect of warming disappeared once the time trend was controlled for. The yield–impact model showed that a 20% fall in yield could raise the footprint of each kilogram of CPO by about 12–20% and increase land demand by 25%.

These conclusions should be read with some limitations in mind. The climate data are national averages, and for Ecuador they include the cold Andean highlands, so they do not fully represent

DOI: 10.54254/2753-8818/2027.39076

conditions in the lowland plantation areas. Yearly data also hide the timing of dry months and the one- to two-year delay in the response of oil palm to drought [13]; only one lag was tested here, and it was not significant. The model did not include management, fertiliser, disease, plantation age, or soil data, which probably explain much of the remaining variation. The residuals were autocorrelated, which is why Newey–West standard errors were also reported. Finally, the LCA results come from a sensitivity model based on assumed values of f and OER, not from a full inventory of Ecuadorian plantations and mills.

Future research should use plantation-level or provincial climate and yield data, test lagged drought effects more fully, and collect local LCA inventory data from Ecuadorian plantations and mills. For policymakers and producers, efforts to protect yields from disease and climate stress could also help reduce the environmental impact of palm oil production.

## Data availability

Yield data: FAOSTAT Crops and Livestock Products [8], accessed through Our World in Data [21]. Climate data: CRU TS 4.07 country averages [16] from the World Bank Climate Change Knowledge Portal [22]. The derived variables (PET, water deficit, and moisture index) and the analysis scripts are available from the author on request.

## References

[1] IPCC. (2022). Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
[2] Wulandari, R., Abas, A., & Abdullah, A. (2025). Understanding the impact of climate change on oil palm plantation: A systematic literature review. *Frontiers in Sustainable Food Systems, 9*, 1621217.
[3] Lobell, D. B., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science, 333*(6042), 616–620.
[4] Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D. B., Huang, Y., Huang, M., Yao, Y., Bassu, S., Ciais, P., Durand, J.-L., Elliott, J., Ewert, F., Janssens, I. A., Li, T., Lin, E., Liu, Q., Martre, P., Müller, C., … Asseng, S. (2017). Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences, 114*(35), 9326–9331.
[5] Corley, R. H. V., & Tinker, P. B. (2016). *The oil palm* (5th ed.). Wiley Blackwell.
[6] Paterson, R. R. M., Kumar, L., Taylor, S., & Lima, N. (2015). Future climate effects on suitability for growth of oil palms in Malaysia and Indonesia. *Scientific Reports, 5*, 14457.
[7] Couvreur, T. L. P., & Baker, W. J. (2013). Tropical rain forest evolution: Palms as a model group. *BMC Biology, 11*, 48.
[8] Food and Agriculture Organization of the United Nations. (2025). FAOSTAT: Crops and livestock products [Data set]. *FAOSTAT*. https://www.fao.org/faostat/en/#data/QCL
[9] Meijaard, E., Brooks, T. M., Carlson, K. M., Slade, E. M., Garcia-Ulloa, J., Gaveau, D. L. A., Lee, J. S. H., Santika, T., Juffe-Bignoli, D., Struebig, M. J., Wich, S. A., Ancrenaz, M., Koh, L. P., Zamira, N., Abrams, J. F., Prins, H. H. T., Sendashonga, C. N., Murdiyarso, D., Furumo, P. R., … Sheil, D. (2020). The environmental impacts of palm oil in context. *Nature Plants, 6*(12), 1418–1426.
[10] Pirker, J., Mosnier, A., Kraxner, F., Havlík, P., & Obersteiner, M. (2016). What are the limits to oil palm expansion? *Global Environmental Change, 40*, 73–81.
[11] Sayer, J., Ghazoul, J., Nelson, P., & Boedhihartono, A. K. (2012). Oil palm expansion transforms tropical landscapes and livelihoods. *Global Food Security, 1*(2), 114–119.
[12] Woittiez, L. S., van Wijk, M. T., Slingerland, M., van Noordwijk, M., & Giller, K. E. (2017). Yield gaps in oil palm: A quantitative review of contributing factors. *European Journal of Agronomy, 83*, 57–77.
[13] Carr, M. K. V. (2011). The water relations and irrigation requirements of oil palm (Elaeis guineensis): A review. *Experimental Agriculture, 47*(4), 629–652.
[14] Furumo, P. R., & Aide, T. M. (2017). Characterizing commercial oil palm expansion in Latin America: Land use change and trade. *Environmental Research Letters, 12*(2), 024008.

DOI: 10.54254/2753-8818/2027.39076

[15] Torres, G. A., Sarria, G. A., Martinez, G., Varon, F., Drenth, A., & Guest, D. I. (2016). Bud rot caused by Phytophthora palmivora: A destructive emerging disease of oil palm. *Phytopathology, 106*(4), 320–329.
[16] Harris, I., Osborn, T. J., Jones, P., & Lister, D. (2020). Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. *Scientific Data, 7*, 109.
[17] Sari, D. A. P., Nikmah, M., & Sasongko, N. A. (2023). Life cycle assessment in the production process of crude palm oil (CPO) on palm oil plantation and mills. *International Journal of GEOMATE, 25*(111), 177–184.
[18] Schmidt, J. H. (2015). Life cycle assessment of five vegetable oils. *Journal of Cleaner Production, 87*, 130–138.
[19] Stichnothe, H., & Schuchardt, F. (2011). Life cycle assessment of two palm oil production systems. *Biomass and Bioenergy, 35*(9), 3976–3984.
[20] Zen, M. R., Putra, A. A., Mujahidah, U., Napitupulu, M. M. M., Noviarini, C., & Rahman, M. M. (2024). Life cycle assessment in crude palm oil production: Optimization of oil extraction rate. *Jurnal Presipitasi: Media Komunikasi dan Pengembangan Teknik Lingkungan, 21*(2), 513–526.
[21] Ritchie, H., Rosado, P., & Roser, M. (2023). Agricultural production. *Our World in Data*. https://ourworldindata.org/agricultural-production
[22] World Bank. (2025). Climate change knowledge portal: Ecuador and Brazil, CRU TS 4.07 historical climate data [Data set]. https://climateknowledgeportal.worldbank.org/
[23] Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements* (FAO Irrigation and Drainage Paper No. 56). Food and Agriculture Organization of the United Nations.
[24] Hargreaves, G. H., & Samani, Z. A. (1985). Reference crop evapotranspiration from temperature. *Applied Engineering in Agriculture, 1*(2), 96–99.
[25] Thornthwaite, C. W. (1948). An approach toward a rational classification of climate. *Geographical Review, 38*(1), 55–94.
[26] Wooldridge, J. M. (2020). *Introductory econometrics: A modern approach* (7th ed.). Cengage Learning.
[27] Newey, W. K., & West, K. D. (1987). A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica, 55*(3), 703–708.
[28] Zolkarnain, N. (2025). Environmental assessment of fatty acids production from palm oil using life cycle approach. *Journal of Oil Palm Research, 37*(3), 560–572.