**Projected impacts of climate change on palm oil production in Côte d'Ivoire**

**Abstract**

The effects of climate change scenarios were analyzed for the central and southern oil palm production regions of Côte d'Ivoire. Temperature and precipitation variables were forecast for the periods 2021-2050 and 2041-2070, based on the Representative Concentration Pathways (RCPs) 4.5 and 8.5 greenhouse gas concentration scenarios, in comparison to the 1980-2010 reference period. The results indicated that, besides a considerable frequency of hot days and water scarcity, potentially threatening oil palm production in marginal sections of the Centre region, the climatic parameters suggest standard production conditions for oil palm in these two regions. The risks linked to diseases and pests could be similar or possibly mitigated. In the southern region, climatic variations seem to have no effect on oil palm production. To enhance their resilience, it is crucial to educate oil palm producers on the significance of utilizing drought-resistant planting material, adhering to good agricultural practices and implementing agroforestry techniques. Enhancing producers' access to meteorological information would also be essential.

**Keywords:** Climate change scenarios, impact, oil palm, meteorological information

**Introduction**

Climate change poses a significant threat to all humanity [1]. The main causes are large-scale emissions of greenhouse gases (GHGs) into the atmosphere, which are modifying rainfall patterns and global temperatures [2]. Climate change, which is scientifically undeniable, impacts all sectors, albeit with regional variations [3]. This phenomenon impacts ecosystems and people's livelihoods, particularly in developing nations [4]. Although Africa's contribution to greenhouse gas emissions is minimal, the continent remains vulnerable to the harmful effects of climate change [5]. This circumstance has emerged as a new threat to growth and sustainable development in Africa [6]. Agriculture is among the sectors most impacted by climate change [4], [7]. Agricultural production will decline for farmers due to rising temperatures, shifting seasons and irregular rainfall [8]. Furthermore, due to the prevalence of rainfed agriculture and the lack of resources for adaptation strategies, agriculture is increasingly susceptible to climate change [9]. Recent studies in West Africa forecast considerable unpredictability in climatic conditions for agriculture [10], [11], particularly for oil palm (*Elaeis guineensis*), impacting the livelihoods of over one million producer households [46]. Côte d'Ivoire is the second largest producer and the foremost exporter of palm oil in West Africa, representing over 45% of its production [12]. Like other palm oil-producing nations, it is experiencing the repercussions of climate change, notwithstanding the magnitude of its production. This phenomenon influences temperature and precipitation, hence affecting the physiology of the oil palm and production variables [13]. All stakeholders in the oil palm sector are experiencing the impacts of climate change, as minimal climate information is available and accessible for application within their intervention zones [14], [15]. Communities cultivating oil palms are inadequately informed and taught methods to mitigate the impacts of climate change on their crops. This situation makes it difficult to make informed decisions in a changing climate. To enhance the resilience of oil palm producers’ cooperatives and their member families against climate change impacts, future climate change scenarios were formulated and analyzed for oil palm production in Côte d'Ivoire. Concluding the analysis, recommendations were made to enhance the ability of oil palm producers to adapt to the impacts of climate change.

**Material and Methods**

**1- Concepts of climate scenarios**

A climate scenario is a plausible description of the future condition of the climate [16]. According to the Ouranos report [17], climate scenarios are produced by integrating in-situ observations as a reference dataset with climate forecasts for specific climate variables. This combination results in a climate scenario, or a series of values related to this variable over a period spanning several decades and with a specified periodicity. Climate models designate greenhouse gas (GHG) emission scenarios as Representative Concentration Pathways (RCPs) to illustrate future radiative forcing. Numerous groups of RCP models exist, with RCP 4.5 and RCP 8.5 being the most prevalent, which correspond respectively to a decrease in GHG emissions (optimistic scenario) and a constant increase in emissions throughout the century (pessimistic scenario). These models belong to the CORDEX (Coordinated Regional Climate Downscaling Experiment) - Africa domain. In the present study, the RCP 4.5 and RCP 8.5 models were used to develop climate scenarios for the oil palm zone in Côte d'Ivoire. The projections represent probable values included within a confidence interval [18].

**2- Study area and data analysis**

The study area is the oil palm-growing zone of Côte d'Ivoire, divided into two climatic regions: the central region (located between 5.5° and 8° N latitude) and the southern region (situated below 5.5° N latitude) (Figure 1).

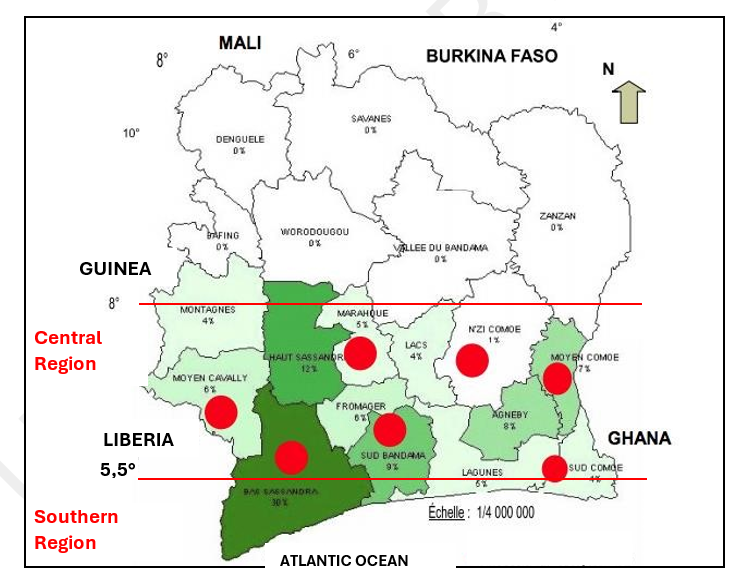
In both climate areas, the anticipated climate variables include temperature and precipitation during two-time frames (2021 to 2050 and 2041 to 2070), in comparison to the reference period of 1981 to 2010. The study began in 2019, and as the data for the 2011-2020 decade is not complete, the 1991-2020 normal has not been used as a reference. The thirty (30) year time horizon adheres to the established norm in climatology [19]. This period is typically sufficient to acquire representative climatic statistics, except for extreme and infrequent events [17]. For each horizon, the temperature indices calculated include the average temperature, the average minimum daily temperature (the lowest temperature recorded among the 24-hourly values for the day), the average maximum daily temperature (the highest temperature recorded among the 24-hourly values for the day), and the count of hot days (the number of days in the year with a maximum daily temperature exceeding 33°C). The estimated indices for rainfall include cumulative yearly rainfall, the number of wet days (5 mm/day), water deficit, as well as the start and end dates and duration of both the long and short rainy seasons. The impact of climate change on oil palm production was analyzed based on the differences in the indices. The agronomic parameters evaluated were oil palm physiology (plant survival post-planting, growth, flowering, fruiting, and bunches size), soil fertility and health (microfauna and microflora), and crops associated with oil palm cultivation. The impact of climate change on the progression of fusariosis and basal rot of the stipe caused by Ganoderma sp. was examined in relation to oil palm diseases. The analysis focused on *Coelaenomenodera lameensis*, *Oryctes monoceros*, Temnoshoites, Prosoestus spp., *Recilia mica*, and defoliating caterpillars in relation to pests. The socio-economic aspect was considered by examining the gender-specific effects on the activities of women oil palm producers in relation to climate change. The FAO [20] indicates that rural women are significantly vulnerable to climate risks due to various constraints, and their knowledge and skills play a crucial role in enhancing resilience.

Figure 1: Oil palm production area in Côte d'Ivoire

Source: Adapted from the Directorate of Agriculture in Côte d’Ivoire (Ouranos, 2021)

**Results**

**1- Changes in climatic parameters in the oil palm-growing zone between 2021 and 2070**

Climate change scenarios are presented for the central (Table 1) and southern (Table 2) oil palm cultivation regions of Côte d'Ivoire. Analysis of the scenarios indicates that, during the next fifty years (2021 to 2070), there will be an increase in temperature (0.6 to 2°C on average) relative to the 1980-2010 reference values for the two regions (25.7°C in the Centre and 25.2°C in the South). Nonetheless, this increase in temperature would be more pronounced in the Centre region, with a greater frequency of hot days (ranging from 77 to 142 days per year) in contrast to 51 days during the reference period (Figure 2). In contrast, the annual count of hot days in the Southern region would be reduced (ranging from 7 to 47 days/year) and would fall below the 51 hot days that oil palm can tolerate. The annual cumulative rainfall in the Centre area (1317 to 1533 mm/year) and the South region (1800 to 2164 mm/year) falls within the range (1200 to 2000 mm/year) favorable to oil palm growing. The primary rainy season would start earlier or later in the Centre region and will begin later in the South, while the short rainy season will initiate early in both regions

**2- Impact of climate change scenarios on the development and growth of oil palm from 2021 to 2070**

The impact of climate scenarios on oil palm development was analyzed, including the establishment of oil palm plantations (seedling survival post-planting), growth, flowering, fruiting, and bunches production. Concerning the temperature parameter, the rise in daily temperatures (averaging between 0.6 to 2°C relative to the reference values of 25.7°C in the Centre region and 25.2°C in the South region) and the achievement of maximum temperatures (32.4°C in the Centre region and 30.8°C in the South region) would remain advantageous for oil palm development, specifically for the survival of seedlings post-planting, as well as for growth, flowering, fruiting, and bunches production. The average and maximum values fall within the optimal temperature range (18 to 34°C) for cultivating oil palm in Côte d'Ivoire. Physiological effects on the oil palm occur exclusively at temperatures exceeding 35°C.

The cumulative rainfall in the southern region, ranging from 1800 to 2164 mm per year, remains conducive to the oil palm cultivation.

Table 1. Projected evolution of climate parameters from RCP 4.5 and RCP 8.5 models in the Central Oil Palm Production Region of Côte d’Ivoire for the period 2021-2070

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Climatic parameter indices | Normal value for oil palm | Reference Period  1981-2010 | Horizon 2021-2050 | Horizon 2041-2070 |
| Tmin | 18 | 22.6 | [23.2 – 23.9] | [23.5 – 24.8] |
| Tmax | 36 | 30.3 | [31. – 31.6] | [31.3 – 32.4] |
| Tav | 25-26 | 25.7 | [26.3 – 26.9] | [26.6 – 27.7] |
| Rca | [1600-1800] | 1328 | [1317 – 1491] | [1315 -1533] |
| WD | - | 272 | 283-309 | 267-285 |
| NRD | 89 | 89 | [83 - 99] | [81 - 100] |
| SLRS | 15 march | 7 april | [2 april – 14 april] | [31 march – 15 april] |
| ELRS | 15 july | 31 july | [29 j july – 1st august] | [29 july – 1er august] |
| DLRS | 122 | 116 | [107 – 120] | [108 – 121] |
| SSRD | 15 september | 26 august | [22 august – 27 august] | [21 august – 26 august] |
| ESRS | 11 november | 17 november | [11 nov. – 20 nov.] | [12 nov. – 22 nov.] |
| DSRS | 65 | 82 | [79 – 89] | [79 – 83] |

*Tmax = Average daily maximum temperature SLRS = Start of the Long Rainy Season*

*Tmin = Average daily minimum temperature ELRS = End of the Long Rainy Season*

*Tav = Average daily temperature DLRS = Duration of the Long Rainy Season (days)*

*Rca = Annual cumulative rainfall RCA SSRD = Start of the Short Rainy Season*

*NRD = Number of rainy days ESRS = End of the Short Rainy Season*

*WD = Water deficit DSRS = Duration of the Short Rainy Season (days)*

Table 2. Projected evolution of climate parameters from RCP 4.5 and RCP 8.5 models in the Southern Oil Palm Production Region of Côte d’Ivoire for the period 2021-2070

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Climatic parameter indices | Normal value for oil palm | Reference Period  1981-2010 | Horizon 2021-2050 | Horizon 2041-2070 |
| Tmin | 18 | 23 | [23,6 – 24.2] | [23.9 – 25] |
| Tmax | 36 | 28.8 | [29.4 - 30] | [29.7 – 30.8] |
| Tav | 25-26 | 25.2 | [25.8 – 26.4] | [26.1 – 27.2] |
| NHD | 51 | 2 | [7 - 17] | [12 - 47] |
| Rca | [1600-1800] | 1888 | [1800 – 2115] | [1812 – 2164] |
| WD | - | 0 | 0 | 0 |
| NRD | 89 | 130 | [115 - 152] | [112 - 154] |
| SLRS | 15 march | 27 march | [25 march – 3 april] | [27 march – 5 april] |
| ELRS | 15 july | 30 july | [28 july – 4 august] | [27 july – 1st august] |
| DLRS | 122 | 125 | [116 – 131] | [115 – 128] |
| SSRD | 15 september | 31 august | [23 august – 1st sept] | [22 august – 31 august] |
| ESRS | 11 november | 19 november | [14 nov. – 23 nov.] | [14 nov. – 23 nov.] |
| DSRS | 65 | 79 | [75 – 88] | [78 – 89] |

*Tmax = Average daily maximum temperature SLRS = Start of the Long Rainy Season*

*Tmin = Average daily minimum temperature ELRS = End of the Long Rainy Season*

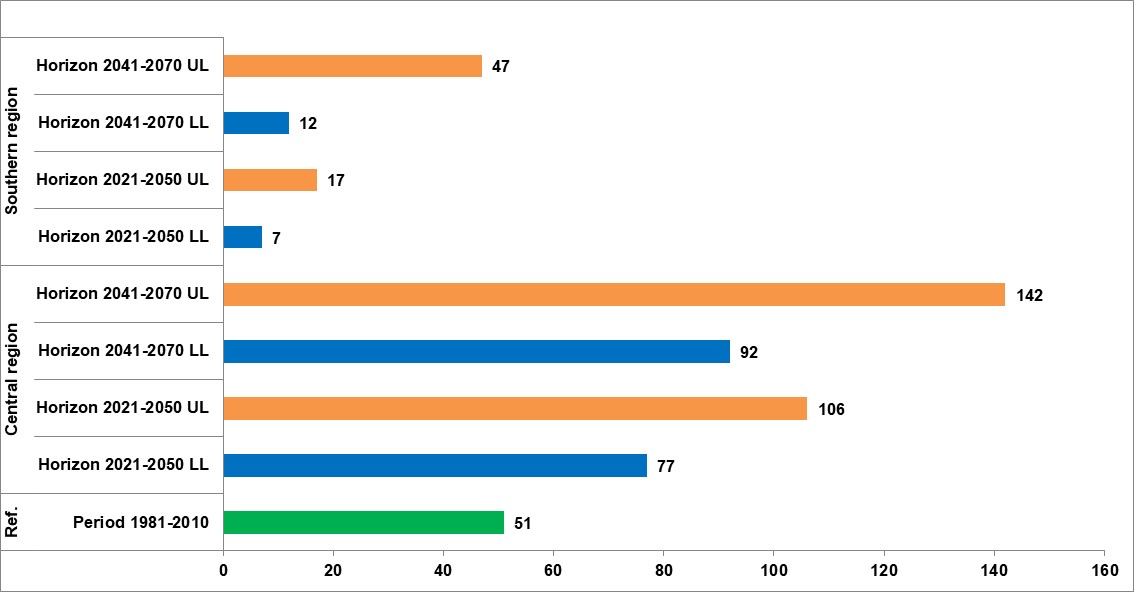
*Tav = Average daily temperature DLRS = Duration of the Long Rainy Season (days)*

*Rca = Annual cumulative rainfall RCA SSRD = Start of the Short Rainy Season*

*NHD = Number of hot days NRD = Number of rainy days*

*ESRS = End of the Short Rainy Season WD = Water deficit*

*DSRS = Duration of the Short Rainy Season (days)*



**Figure 2:** Fluctuation in the number of hot days based on horizons in the Central and Southern regions of oil palm production in Côte d'Ivoire.

*NHD/year = Number of Hot Days per year; LL: Lower limit; UL: Upper limit*

The annual precipitation required for oil palm development ranges from 1,800 to 2,400 mm/year, compared with a reference value of 1,888 mm/year in the southern region.

As for the central region, the cumulative rainfall (1317 to 1533 mm/year), is not favorable for optimal oil palm development. The water deficits recorded will range from 283 to 309 mm for the period 2021-2050 and from 267 to 285 mm for the period 2041-2070.

The estimates for the number of rainy days (≥ 5 mm/day) indicate that the Centre region would experience 83 to 100 days per year, while the South region will have 115 to 154 days per year. These figures are conducive to optimal oil palm development, in contrast to the reference values of 89 days and 130 days per year.

The elevated frequency of hot days (temperatures over 33°C) may adversely affect oil palm cultivation, particularly with for the establishment of new oil palm plantation, growth, oil palm development, flowering, fruiting, and bunches production. Significant oil palm mortality will be evident throughout the juvenile phase in both field and production settings, due to the oil palm's extreme sensitivity to water deficiency. In other instances, leaf yellowing, chlorosis, palm necrosis, and stunting result in diminished photosynthesis, thereby hindering oil palm growth. Such conditions may hinder the establishment of new oil palm plantations.

Elevated temperatures correlate with diminished photosynthesis, abbreviated leaf longevity and reduced useful soil water reserves, resulting in lower bunches and a loss of palm oil quality.

An escalation in the frequency of hot days would consequently be detrimental to the production of bunches, as excessive stress would result in a significant rate of abortion of female inflorescences and, conversely, an augmentation in the number of male inflorescences.

The temperature and precipitation in the southern region will remain conducive to oil palm development, flowering, fruiting and bunches production. Nonetheless, a sudden increase in temperature could negatively impact the quality of the bunches.

In the Central region, due to the elevated frequency of hot days, locations such as Haut Sassandra, Marahoué, Bélier, N'zi, Moronou, and Indénié Djuablin, presently regarded as marginal for oil palm cultivation, will become unfit for oil palm production without the implementation of adaptation methods. Climate change may result in the abandonment of these marginal regions and compel oil palm cultivators to relocate to more suitable areas, hence intensifying strain on soil and forests and give rise to numerous land conflicts.

In the southern region, the incidence of hot days remains below the standard 51 hot days required for oil palm, hence there would be no adverse impact on its growth.

**3- Impact of climate variability scenarios on soil health and fertility from 2021 to 2070**

The rise in the frequency of hot days would adversely affect soil health. Indeed, this climatic change will diminish vegetation cover and agricultural productivity, while facilitating the proliferation of barren regions. A comparatively warm climate promoted biological activity (microflora and microfauna) in the soil, so accelerating the decomposition of organic materials and consequently enhancing the deterioration of the humus. Soil fauna, such as earthworms and termites, could enhance this deterioration process. All these processes will be accelerated by precipitation due to increased humidity and the weakening of organic matter that is prone to decomposition. The repercussions include diminished soil fertility (reduced water retention and cation exchange capability) and a decline in carbon stock. The soil also affects the climate based on its state and utilization. Elevated temperatures can accelerate the decomposition of organic materials by microorganisms. Respiration subsequently accumulates soil, releasing additional CO2, hence exacerbating the impacts of greenhouse gases. This influence is primarily dictated by carbon fluxes and the carbon sequestration function. The carbon from the decomposition of plant detritus and deceased organisms is converted into organic matter in the soil, where fungi and bacteria degrade it into partially inorganic byproducts (CO2, H2O, NH4+, NO3-, P, S, Ca, Mg, Fe, etc.). This mineralization process releases CO2 into the atmosphere. The soil also releases two additional greenhouse gases via microbial decomposition processes: methane (CH4) and nitrous oxide (N2O). In the Central region, characterized by a maximum daily temperature of 32.4°C and a significant number of hot days (77 to 142 days per year), there would be a reduction in the availability of microorganisms and carbon in the soil, resulting in diminished soil fertility. In the Southern region, characterized by lower daily temperatures (30.8°C) and a limited number of hot days (ranging from 7 to a maximum of 47 days per year), there would, conversely, be a sustained availability of microbes and carbon in the soil, hence preserving soil fertility levels.

**4- Impact of climate variability scenarios on the main diseases and pests of oil palm from 2021 to 2070**

The climate scenario projected for the central and southern regions of Côte d'Ivoire over the next 50 years was utilized to evaluate the progression of primary oil palm diseases (fusarium wilt, basal stem rot caused by Ganoderma sp.) and significant pests (*Coelaenomenodera lameensis*, *Oryctes monoceros*, Temnoshoites, and defoliating caterpillars) affecting oil palm plantation.

In the Central region, maximum temperatures over 31 °C would be detrimental to the development of the main pathologies of oil palm. Oil palm diseases are primarily attributed to phytopathogenic fungus, including *Fusarium oxysporum* f. sp. elaeidis and Ganoderma sp.

At 30 °C, fungi of the genus Fusarium, like numerous other fungi, often diminish due to the suppression of spore germination (reproductive structure). Furthermore, at temperatures exceeding 31 °C, the likelihood of the emergence of primary oil palm diseases will diminish. Moreover, the increase in the frequency of hot days, ranging from 77 to 106 days by 2021-2050 and from 92 to 142 days by 2041-2070 in the Central zone, would adversely affect the emergence of diseases and unfavorable to the proliferation of pests. Indeed, the lack of water resulting from warming would limit the development of oil palms, hence diminishing the food supply for pests. Consequently, the risks of insect proliferations may be diminished. The forecasts for cumulative rainfall indicate a range of 1317 to 1533 mm/year in the Centre region and 1800 to 2164 mm/year in the South region. Additionally, the anticipated number of rainy days (≥ 5 mm/day) is projected to be between 83 to 100 days in the Centre region and 115 to 154 days in the South region, which would be conducive to the proliferation of primary diseases and significant pests affecting oil palm cultivation. The observations at the oil palm plantation may resemble those we are presently recording. The anticipated postponement of the wet season in the Centre region may create adverse conditions for the proliferation of defoliating caterpillars. In the Southern area, the predicted temperature and precipitation conditions would be favorable to the development of the main diseases and major pests of the oil palm. The anticipated postponement of the wet season in the Centre zone appears detrimental to the proliferation of defoliating caterpillars.

**5- Impact of climate variation scenarios on gender involvement in oil palm cultivation activities by 2021-2070**

The analysis of climate change scenarios in relation to oil palm cultivation reveals that, particularly in the Central zone, global warming may have a detrimental effect on yield, bunches production, and farmers' incomes. The amount of poverty in rural regions will rise because of the deterioration of arable land and the resulting decrease in soil fertility, particularly for the most vulnerable social groups namely women and children. Poverty is expected to rise because of climate change, which will also intensify inequities and prejudice. It is likely to worsen the vulnerabilities and limitations that women will experience. In fact, they typically do domestic duties that rely on natural resources like trees and water. Waterways, fuelwood availability, and subsistence crops are all impacted by rising temperatures, which may increase the workload of women or make their jobs more difficult and time-consuming. When climate change affects their livelihoods and they are unable to fulfill their position as breadwinners, men may also suffer from severe worry and stress.

**Discussion**

The analysis of climatic scenarios indicates a rise in the average temperature of 2°C over the next fifty years in Côte d’Ivoire. This fluctuation aligns with the increasing trend in global average temperature attributable to CO2 and other greenhouse gas emissions in the atmosphere [5]. Temperature significantly influences oil palm growth, and a slight increase might positively affect plant development by providing essential thermal energy [14], [21]. This study demonstrates that climate change will have a more pronounced effect on oil palm cultivation in the Central region compared to the South region. Indeed, the growth and sex ratio of oil palm are negatively impacted by lack of water brought on by prolonged drought or low rainfall, as confirmed by Caliman [22] and Corley and Tinker [23]. Moreover, elevated mortality rates of palm trees are notably recorded during the establishment phase in field due to the palm tree's pronounced sensitivity to water deficiency [24]. According to these scientists, inadequate water availability leads to the closure of stomata, obstructing gas exchange and photosynthesis, resulting in an accumulation of unopened leaves [25]. A sustained water deficit will also result in a significant decline in production within the bunches, attributed to an elevated rate of female inflorescence abortion and, conversely, an increase in male inflorescences [26]. A water deficit of 100 mm typically leads to a reduction of around 10% in the potential yield of oil palm plantation, resulting in somewhat dried fruits with partial ripening on the bunches. The dehydration of fruit might result in the total desiccation of the bunches, causing a notable decrease in the oil extraction rate per bunch [27]. The study conducted by Bambara et al. [28] established that, under these circumstances, barren patches will proliferate. Several other authors [29], [30] have demonstrated that this will lead to diminished soil fertility and a decline in carbon stocks.

Regarding pests and diseases, Dossa et al. [31] confirmed that the fungus *Fusarium oxysporum* f. sp. elaeidis (Foe), which causes oil palm fusarium wilt, loses its ability to survive at high temperatures (33.95 ± 0.36 °C). According to Aneni et al. [32] and Hala et al. [33], the principal palm pests, including *Coelaenomenodera lameensis*, *Prosoestus minor*, and *Prosoestus sculptilis*, decrease in number when the number of hot days increases due to lack of water. These different studies indicate that rising temperatures are detrimental to the emergence of diseases and the proliferation of pests in oil palm agriculture.

Several studies have also confirmed the influence of climate change on palm farming in various palm oil-producing countries, notably Indonesia and Malaysia [34], [35].

Considering the climate scenarios, the central region of Côte d'Ivoire will have significant impacts characterized by elevated temperatures and reduced precipitation. This region can develop oil palms, but it is essential to implement climate-smart agricultural practices. The southern and western regions will continue to be conducive to oil palm cultivation and dominant by 2030 and 2050; however, they must also implement climate-smart agricultural practices, including the selection of drought-resistant plant materials and the adoption of agroforestry techniques [36], [37].

Numerous studies [38], [39], [40], [41], [42], [43] have shown that, in the absence of adaptation, climate change adversely affects the agricultural sector. The FAO [20] emphasizes the necessity for farmers to recognize the risks associated with climate change and to enhance their adaptive ability. The former can be enhanced by supplying pertinent information to the at-risk population regarding the dangers and repercussions of climate change, while the latter entails technical advancements mostly overseen by public officials, agribusiness, and government entities.

The study conducted by [8] in rural Tanzania highlighted the significance of gender considerations in advancing climate-smart agriculture methods. This research demonstrates a positive correlation between women's empowerment in agriculture and the adoption of climate-smart practices.

Given the probable impacts of climate change on oil palm cultivation, the empowerment of women palm oil producers in Côte d'Ivoire must be enhanced. Research conducted by [44] and [45] indicates that women generally own less land (25% of farms), although representing over half (68%) of the agricultural workers and receiving just 21% of the money derived from agricultural production.

**Conclusion**

The impact of climate change scenarios on oil palm cultivation in Côte d'Ivoire was assessed for the next fifty years. The results indicated that, aside from the elevated frequency of hot days that may lead to the extinction of oil palm cultivation in the presently marginal regions of the Central area, the forecasts for climate indices remain within normal parameters for oil palm production. The dangers associated with diseases and pests may resemble those in the reference scenario or could be decreased.

In the Southern region, climatic fluctuations will not affect the growth of palm trees, nor the spread of diseases and pests in oil palm production, relative to the reference period of 1980-2010. Except for the number of hot days to be feared in the Central region, oil palm cultivation remains feasible in both regions. However, to mitigate climate change effects, it is essential to enhance awareness among oil palm producers regarding climate change impacts, improve their access to meteorological data, promote the use of drought-resistant plant varieties and ensure adherence to best agricultural practices (technical itineraries, integrated pest and disease management and rational land management). Improving water management and control strategies in oil palm cultivation (irrigation) will be essential, as well as adequately enhancing fallow land prior to the establishment of oil palm plantation.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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