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Modelling Longitudinal Trends to Oil Palm Refuges and Oil Palm Mortalities in South America under Future Climate

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Abstract

The tropical rainforest in South America fixes vast amounts of carbon and deforestation has severe consequences for future climate. Palm oil is a valuable commodity and many countries in the region have significant oil palm plantations, the development of which may involve deforestation. The effect of climate change on tropical plant species has been studied insufficiently. Tropical plants should be a priority in global change research since there are no pools of plants living in a hotter climate that are available to replace declining species in tropical lowland. Oil palms are under threat from climate change and it appears they will be very negatively affected in South America, as demonstrated by CLIMEX modelling. Some species of organisms can migrate towards the Poles to encounter more suitable climate. In the tropics this is often difficult because of large distances to climate refuges. Longitudinal trends from east to west to refuges have not often been recorded, although such trends were observed for African oil palm. The current paper uses the CLIMEX model in an informative and innovative manner to illustrate potentially generic patterns of longitudinal change under future climate change. In the present example, longitudinal trends in suitable climate for growing oil palm by comparing current time to 2050 and 2100 are described. The degree to which these represent refuges for growing oil palm are considered, which may affect the sustainability of the oil palm plantations. The scenarios can be checked with reality in the future. Paraguay appears to gain suitability in climate for growing oil palm. Venezuela will have a particularly low level of suitable climate. French Guiana, Surname and Guyana appear to maintain suitable climate. Large losses were determined in west Brazil by 2100. The western countries of Colombia, Peru and Ecuador will suffer severe losses. There appears to be a three-phase trend in suitable climate rather than a single direct longitudinal one. The information may be useful for managing other plants, especially palms, in South America. These data will inform future managers of oil palm in South America and are based on a "no change" scenario.

Keywords: *Elaeis guineensis*; Climate change; Brazil; Colombia; CLIMEX; Longitudinal trend; Sustainability

Introduction

Climate change investigations are limited in scope and do not often consider (a) longitudinal change and (b) a wider range of factors apart from temperature (e.g. precipitation) [1], and considering only change to higher latitudes and temperature underestimates the effects of climate change. Poleward movements and upward shifts in species' climate-related range are easily the most reported [2], although some longitudinal trends have been observed [3].

Cho and Mccarl et al., [4] found that climate explained a longitudinal trend that favoured crops. Successional processes for trees demonstrated a longitudinal effect [2] and they were more sensitive to changes in moisture availability than to temperature. Miller et al., [5] determined that forest responses to climate change were apparent near the western range limit of white spruce in Alaska. Sittaro et al., [6] suggested tree species were predominantly limited in their capacity to track climate warming, supporting concerns that warming will impact negatively forest ecosystems. Paterson [3] found longitudinal trends in Africa of suitable future climate for growing oil palm.

Furthermore, there is a paucity of information on climate change effects on species in the tropics [1,7]. Studies covering large areas are lacking and data on thermoregulatory behaviours do not exist

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for tropical lowland plants. The absence of tropical species from most global climate syntheses is especially dangerous because they are expected to have fundamentally different responses to climate change than temperate counterparts. Tropical plants should be a priority in global change research since there are no pools of plants living in a hotter climate that are available to replace declining species in tropical lowland, leading to tropical lowland biotic attrition with potentially negative consequences for ecosystem functioning [1,8].

The absence of latitudinal temperature gradients within the tropics eliminates pole ward migrations as a survival mechanism for most equatorial species and tropical forest species will be particularly sensitive to global warming [9]. Temperature-sensitive species might extend their ranges to cool refuges, although distances to these are greatest for equatorial species and are particularly large in Africa, for example, and the upper elevations of many tropical mountains. Tropical species are likely to be (a) particularly sensitive to global warming because they are adapted to limited geographic and seasonal variation in temperature, (b) living at, or near, the highest temperatures on Earth before global warming began, and (c) isolated from cool refuges. The distance to the nearest cool refuge exceeds 1000 km for more than 20% of tropical species. In the Northern hemisphere, movements have been estimated at 1.69 km yr^{-1} to higher latitudes [8]. A strong latitudinal temperature gradient averages 1°C for each 145-km change in latitude between the Tropics and Polar Regions but approaches zero between the Tropics of Cancer and Capricorn. An increasing west to east trend of future suitable climate for growing oil palm was observed for oil palm in Africa [3].

Palms are iconic plants [10] which are highly significant to humans and biodiversity [3]. Bernal et al., [11] described the large number of palms in South America although unfortunately *Elaeis guineensis*, the topic of the present paper, is mentioned only once and in relation to wine production in Senegal. The paper discussed the management practices for the other palms. Cosiaux et al., [10] reveal how African palms are likely to be affected detrimentally by climate change from increased greenhouse gasses and consequently, may not survive. It is crucial to understand the climate change threats to these plants. They represent bedrock species in the tropics providing essential ecosystem services to rural people worldwide, although many palms are threatened by over-exploitation and habitat loss. African palm species will experience a decline in climatic suitability in>70% of their current ranges by 2080 [12], reducing to ca. 35% if migration to nearby climatically-suitable sites succeeds. However, this is difficult in latitudinal directions in the tropics because there are no temperature gradients in these directions [9]. Furthermore, losses of important palm habitats such as tropical rain forests are steadily exacerbating the pressures on palm populations. Consequently, palms and their ecosystem functions and services will be highly sensitive to climate change, relevant also to palms in South America.

It is fundamental to comprehend how climate change will affect palms given their socioeconomic and ecological importance. Blach-Overgaard et al., [12] predicted climate suitability losses across open plain and forest associated palms where they occur in Africa. Climate suitability increases were predicted for fewer species in smaller areas. A decline was projected in climate suitability in 70% of their current predicted ranges by 2080 for all palms. Many palms could potentially track suitable climate space by dispersing within 100-km distance of their current range margins. In reality, these gains may not be met due to habitat fragmentation with novel anthropogenic habitats constituting dispersal barriers. Similar forces will occur in South America [11].

Decreasing crop production from climate change is a probability [13]. Ramirez-Cabral et al., [14] indicated that large areas for maize cultivation will suffer from heat and dry stresses that may constrain production. Shabani et al., [15] determined that future climate could favour plant pathogenic *Fusarium oxysporum* threatening more infection of crops. Paterson et al., [16,17] determined that the suitability of future climate will decrease oil palm. Paterson [18-23] described how future climate increases mortality and disease of oil palm in South America and SE Asia (Figure 1).

Oil palm grow in the open plain and the natural forest and most palms only grow in one of these environment: Oil palm cultivation involves deforestation [24,25] and hence the development of oil palm could threaten the forest palms. Vast plantations of oil palm *(E. guineensis)* exist, allowing a large global palm oil industry to develop, with highly significant consequences to the global economy and environment [25]. Palm oil is used in numerous foods, cosmetics, pharmaceuticals, biodiesel and is employed in domestic cooking at very high volumes [17]. Oil palm plantations have detrimental environmental consequences especially with respect to deforestation [25] and the oil and its production, are associated with human health problems [26]. Deforestation to clear ground for oil palm plantations will increase zoonotic human infections [27]. All these factors add to the significance of oil palm.

The first commercial palm oil manufacturing began in Malaysia in 1917 [28] and 85% of palm oil is now produced by Malaysia and Indonesia [29]. Oil palm may be grown increasingly in other countries as suitable land becomes scarce and climate is unconducive to growth in Malaysia and Indonesia. For example, there are only 3×10^5 ha remaining in Malaysia [30] and growing oil palm in Malaysia and Indonesia may become difficult as climate change progresses [20-23,31]. In addition, other nations will produce palm oil to boost their economies, forming potential competitors to Malaysia and Indonesia. Indeed, many countries have plans to increase the amount/area of oil palm grown [16,32,33]. There are highly significant industries in South America with Colombia having the largest [34]. South American states could, in theory, increase their market share [25], although high levels of oil palm cultivation reduce ecosystem function [24].

The selling of palm oil provides a large economic return to many countries throughout the world. The list of commodities of which palm oil is a component is huge and has been described previously, for example, in Paterson [20-23]. South America in particularly important for palm oil within the Americas, with Colombia being the most important producer in the Americas. Other countries have a great deal of potential capacity to produce palm oil, particularly Brazil especially because the climate is highly suitable currently. However, a working document of oil palm industry in Brazil (www.cifor.org/knowledge/publication/5861) indicates that high costs of labour compared to SE Asia may constrain the development of the industry.

Suitable climate for growing OP was determined in Indonesia and Malaysia using modelling techniques that employed temperature, soil moisture and wet stress [16]. As mentioned, often only temperature is employed in other studies thereby limiting their significance. Paterson et al., [17] extended this approach globally and included other countries in South America, where it was apparent that they would be affected detrimentally by the changes. The general trend was for a reduced level of suitable climate in 2050, further reduction by 2070 and even more by 2100. The projections indicate serious consequences to the palm oil industry generally as the climate becomes unsuitable for growing OP. Paterson et al., [17] used modelling techniques employing temperature and moisture parameters such as soil moisture and wet stress. There was a large area of highly suitable climate in South America, extending coast to coast from Brazil to Ecuador. By 2050 and further to 2100 the overall suitable climate for growing oil palm decreased. The projections indicate serious consequences to the palm oil industry generally, and that the climate will become unsuitable for growing oil palm at the same rate, or faster than, Malaysia and Indonesia. However, there was no attempt at more in-depth study of trends within the countries from the maps provided as described in the present paper.

Paterson [20] indicated high mortality of oil palm under climate change in various SE Asian countries. Paterson [21] described high oil palm mortalities in South American countries compared to Malaysia and Indonesia. Mortalities of oil palm in Malaysia were determined [22] and the analysis was extended to include the Malaysian regions. A similar approach was taken for Indonesia where high levels of mortality were determined in many states [23]. Paterson [18] indicated that the serious fungal disease of oil palm, Basal Stem Rot (BSR), would become even more serious after 2050 in Sumatra and that the climate for growing oil palm would deteriorate greatly. Paterson [19] employed similar methodology to produce a postulated scheme of how BSR would advance under future climates in Malaysia. Assessment of BSR in the countries considered in Paterson [20,22,23] were also undertaken and indicated a severe threat from the disease. Finally, a similar procedure was undertaken to determine future incidences of *Phytophthora palmivora* disease of oil palm in the SE Asian and South American countries and a severe threat was indicated in some cases [21].

The current paper employs a CLIMEX model to create informative and innovative scenarios using an additional narrative model to illustrate important generic issues facing agronomy. How suitable climate for the growth of oil palm changes across relevant countries in South America based on the information in Paterson et al., [17] is discussed. There is a paucity of information in the scientific literature on (a) climate effects in tropical countries such as those in South America, (b) the effect of climate change employing other conditions apart from temperature and (c) the longitudinal effects of climate change.

Material and Methods

The CLIMEX mechanistic niche model described in Paterson et al., [17] provided scenarios of suitable climate for growing oil palm under climate change in the South American countries considered in this report and was used to provide information from maps in Paterson et al., [17] for current time, 2050 and 2100 (Figure 1). CLIMEX software is useful for ecological research by incorporating modelling of the potential distributions of species under various climate scenarios and assumes that climate is the paramount determining factor of plant distributions. The model allows the determination of geographically relevant climatic parameters describing the responses of plants to climate and imposes limitations to the geographical distribution of a species and determines seasonal phenology and abundance. The Annual Growth Index (GIA) represents the species growth potential in the favourable season, while the impact of population reduction during an unfavourable season is established by the cold, hot, wet and dry Stress Indices and their interactions. The Ecoclimatic Index (EI), the product of the GIA and Stress Indices, rates the level of suitability for occupation of a particular location or year for a species. The EI is an annual average index, derived from weekly data of the growth and Stress Indices of suitability levels of climatic factors, denoted by a value on the scale 0 to 100. A species can establish when EI>0.

CLIMEX categorised areas according to high suitability, suitability, marginal suitability and unsuitability based on other studies using CLIMEX [17]. In the present study, temperature index; moisture index; cold stress; heat stress; dry stress; wet stress and Degree-day threshold were fitted according to global distribution data, iteratively adjusted to achieve satisfactory agreement between known and projected distributions of the species globally. Detailed justification of these parameters and values used in oil palm modelling are provided in Paterson et al., [16,17].

The oil palm distribution was determined by the Global Biodiversity Information Facility (GBIF) (http://www.gbif.org/, accessed 9 November 2015) and additional literature on the species in CAB Direct (http://www.cabdirect.org/web/about.html, accessed October 2015), and formed the basis for the collection of data on the *E. guineensis* distribution in [17] with 2465 records utilized in fitting the parameters. CLIMEX in conjunction with the A2 Special Report on Emissions Scenarios (SRES) scenario, a mechanistic niche model using CLIMEX software supports ecological research incorporating the modelling of species' potential distributions under differing climate scenarios and assumes that climate is the paramount determining factor of plant and poikilothermal animal distributions. CLIMEX output categorized areas according to highly suitable climate, suitable climate, marginal climate and unsuitable climate based on other studies through CLIMEX.

The maps provided by the analyses were magnified on a computer screen to focus on the regions discussed in the current paper using the Word magnification facility. The percentages of highly suitable and suitable climates were determined by assessing visually the areas of red and yellow in each map, where red represented highly suitable climate and yellow the suitable climate for growing oil palm. These two sets of suitabilities were combined to form the Combined Suitable Climate (CSC) parameter.

The oil palm mortalities of oil palm were determined from especially marginal and unsuitable climate increases. The highly suitable and suitable categories were employed to a lesser extent. CSC data were plotted against each country which was represented by the longitude that represented the mid-point of each country. However, Brazil was divided longitudinally into east and west Brazil, because it is a big country that stretches from east to west of South America. The trend line was drawn using Excel software. The results are based on a "no change" scenario and do not consider any amelioration processes that may occur in the future or if actual climate change is less or more severe than is currently predicted.

Results

The suitability of climate maps for growing oil palm in CT, 2050 and 2100 are provided in Figure 1 for South America. Overall, a decrease in suitability was observed from CT to 2050 and then further until 2100. A longitudinal trend was notobvious by a simple visual examination of the maps, although French Guiana, Surname and Guyana appeared to remain more suitable throughout the periods

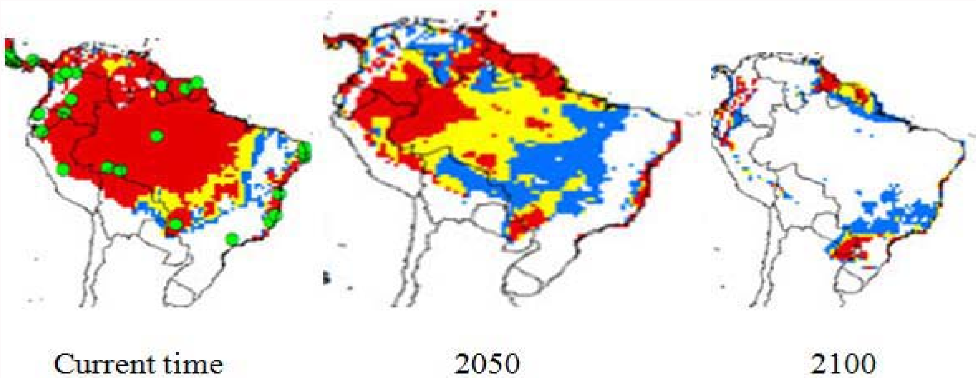

Figure 1: Maps of the relevant South American countries showing the colours representing the climate suitability for growing oil palm from [17]. Red, yellow, blue and white represent highly suitable, suitable, marginal and unsuitable climates respectively.

compared to other countries. The CSC for Paraguay increased in 2050 and further to 2100.

From Figure 2, the CSC for CT was 70% in east Brazil, increasing to 100% in French Guiana and Suriname and was almost that in Guyana. There followed a very large decrease to Paraguay of 3% followed by an increase to Bolivia (35%) and a return to 100% in west Brazil. Thereafter the CSC fell *via* Venezuela, Colombia, Peru and finally Ecuador which was at 40%. A decreasing trend line was obtained from a very high level of 90% in the east of South America to 52% in the west: The average CSC was 69.4%. Figure 3 demonstrates the CSC data for 2050 in which case the average CSC was 49.8%. There is a decreasing trendline from 66% to 38% from east to west South America. The datum for east Brazil was much lower at 25% compared to the CT figure. The CSC for French Guiana and Suriname remained at 100%. There followed a decreasing trend until Bolivia which was at 15%. West Brazil had a value of 60% which decreased rapidly to 2% for Venezuela. Thereafter, the values increase substantially to Colombia (45%), Peru (58%) and finally Ecuador at 40%. There was a decreasing trend of CSC from east to west South America from 34% to 5% with an average CSC of 17.7% for 2100 (Figure 4). CSC fell to 2% for east Brazil and then there was a linear increase to 60% for Guyana *via* French Guiana and Suriname. There was a decrease to 35% for Paraguay and then to 0% for Bolivia and 3% for west Brazil and then the values remained very low for the countries further west.

The changes in CSC from CT to 2050 are illustrated in Figure 5. There was a slightly increasing trend from east to west South America and most countries had reduced CSC except Paraguay, which had an increase to 17%. There was no change for French Guiana, Suriname and Ecuador and Peru had a decrease of -2%. Venezuela had a very large decrease of -86% and east Brazil, west Brazil and Colombia had large decreases. The changes in CSC from CT to 2100 are provided in Figure 6. There was almost no trend in CSC from east to west South America. Almost all countries had very large decreases in CSC from CT to 2100 except Paraguay which had an increase to 32%. The decreases for Guyana, Bolivia and Ecuador were moderate.

No mortalities from poor climate were determined for French Guiana, Surname, Paraguay, Peru and Ecuador. High, or very high, mortalities were determined for Guyana, west Brazil, Bolivia and Venezuela. Moderate mortalities were calculated for the remaining countries or region. Again, the mortalities for 2100 (Figure 7) mirrored the CSC for 2100 (Figure 6). Very high mortalities were obtained for all counties except Paraguay where no mortalities from poor climate were determined.

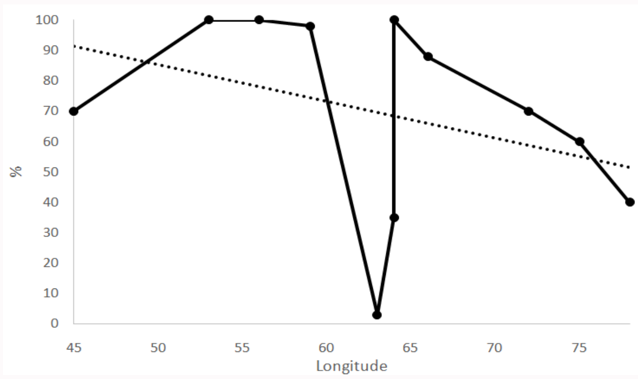

Figure 2: Combined suitable climate in current time for the countries in South American considered. Longitudes employed for Ecuador was 78º, Peru 75º, Colombia 72º, Venezuela 66º, west Brazil 64º, Bolivia 64º, Paraguay 63º, Guyana 59º, Suriname 56º, French Guiana 53º, and east Brazil 45º. The trend line is the broken line.

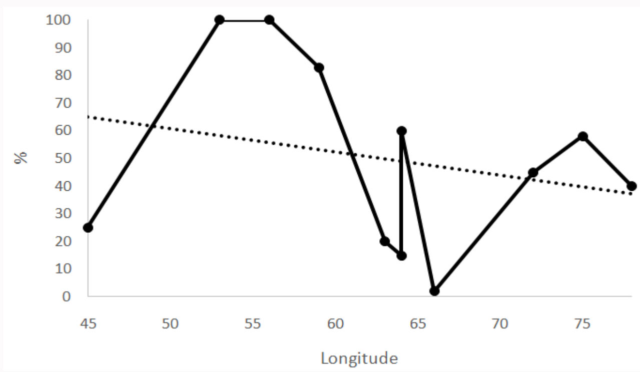

Figure 3: Combined suitable climate in 2050 for the countries in South American considered. Longitudes employed for Ecuador was 78º, Peru 75º, Colombia 72º, Venezuela 66º, west Brazil 64º, Bolivia 64º, Paraguay 63º, Guyana 59º, Suriname 56º, French Guiana 53º, and east Brazil 45º. The trend line is the broken line.

The percentage changes in CSC of the original area for each country in CT compared to that in 2050 are provided in Figure 8. The decrease for east Brazil was -64% and there were no French Guiana and Suriname, with Guyana having a moderate decrease of -15%. There was a massive increase of 570% for Paraguay. Thereafter there was a very sharp decrease from Paraguay to Venezuela which was at

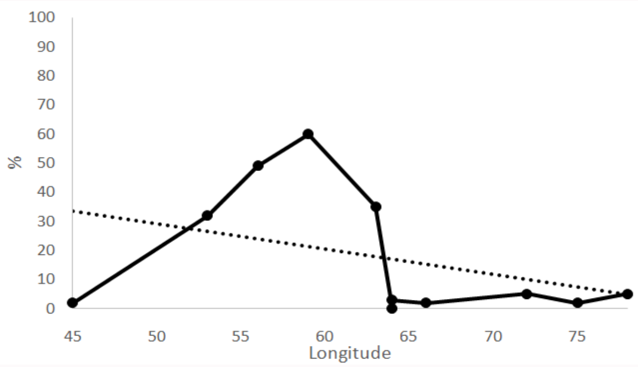

Figure 4: Combined suitable climate in 2100 for the countries in South American considered. Longitudes employed for Ecuador was 78º, Peru 75º, Colombia 72º, Venezuela 66º, west Brazil 64º, Bolivia 64º, Paraguay 63º, Guyana 59º, Suriname 56º, French Guiana 53º, and east Brazil 45º. The trend line is the broken line.

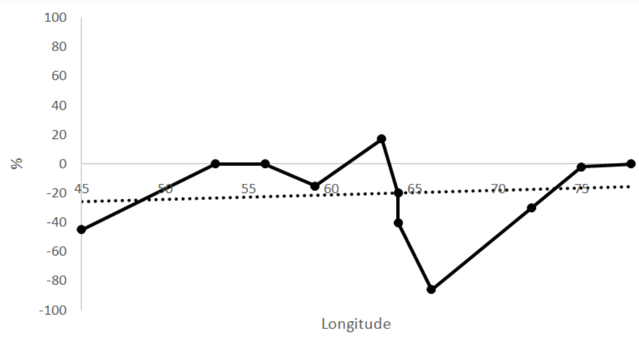

Figure 5: Change in CSC from climate in 2050 compared to current time. Longitudes employed for Ecuador was 78º, Peru 75º, Colombia 72º, Venezuela 66º, west Brazil 64º, Bolivia 64º, Paraguay 63º, Guyana 59º, Suriname 56º, French Guiana 53º, and east Brazil 45º. The trend line is the broken line.

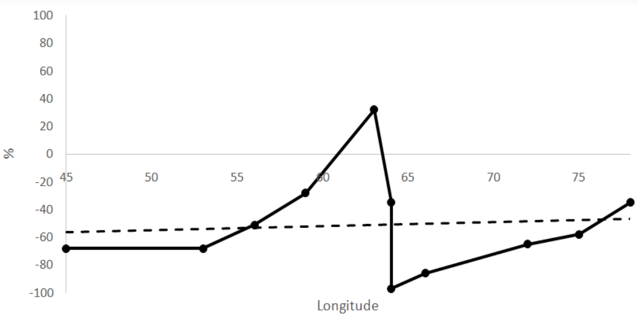

Figure 6: Change in CSC from climate in 2100 compared to current time. Longitudes employed for Ecuador was 78º, Peru 75º, Colombia 72º, Venezuela 66º, west Brazil 64º, Bolivia 64º, Paraguay 63º, Guyana 59º, Suriname 56º, French Guiana 53º, and east Brazil 45º. The broken line is the trend.

-98% with west Brazil and Bolivia being at -40 and -57%. An increase in CSC followed through Colombia to Ecuador and Peru which had a very small decrease and no change respectively.

There was much change by 2100 in the original area in CT compared to that for 2100, except for Guyana and Venezuela where only small decreases were observed (Figure 9). The change again remarkable at 1070% as the climate became much more suitable by 2100. There was an increasing trend in percentage change of original

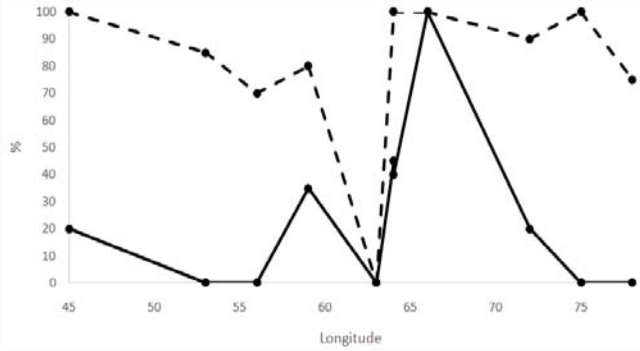

Figure 7: Mortality of oil palm in South America. Longitudes employed for Ecuador was 78º, Peru 75º, Colombia 72º, Venezuela 66º, west Brazil 64º, Bolivia 64º, Paraguay 63º, Guyana 59º, Suriname 56º, French Guiana 53º, and east Brazil 45º. The unbroken line is mortalities for 2050 and the broken line is for 2100.

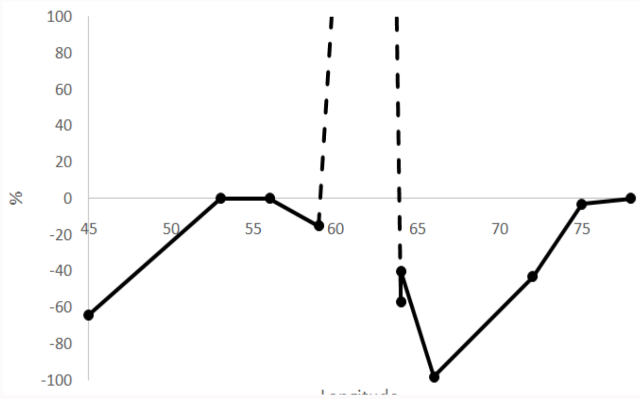

Figure 8: Change in the original area of CSC in each country in current time compared to 2050. Longitudes employed for Ecuador was 78º, Peru 75º, Colombia 72º, Venezuela 66º, west Brazil 64º, Bolivia 64º, Paraguay 63º, Guyana 59º, Suriname 56º, French Guiana 53º, and east Brazil 45º. The broken line is for Paraguay which goes beyond 100%.

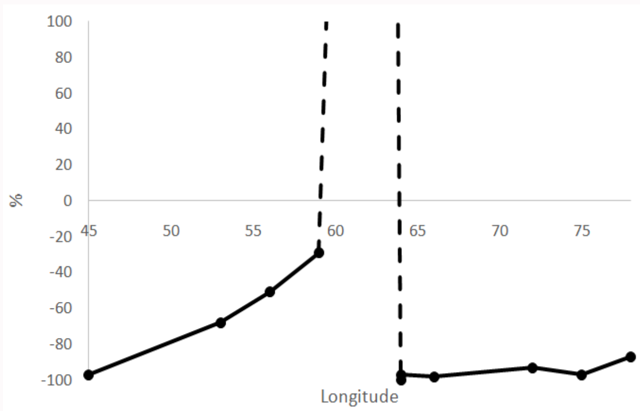

Figure 9: Change in the original area of CSC in each country in current time compared to 2100. Longitudes employed for Ecuador was 78º, Peru 75º, Colombia 72º, Venezuela 66º, west Brazil 64º, Bolivia 64º, Paraguay 63º, Guyana 59º, Suriname 56º, French Guiana 53º, and east Brazil 45º. The broken line is for Paraguay which goes beyond 100%.

area of CSC from CT to 2100 from east Brazil (-100%) until Paraguay. There was a dramatic decrease to virtually 100% for the remaining countries and west Brazil.

Discussion

The current paper employs a CLIMEX model to create informative and innovative scenarios using a narrative model to illustrate important common themes facing agriculture. How suitable climate for the growth of oil palm changes across relevant countries in South America is described. Other crops will be subjected to such change pressure.

The maps of suitable climate for oil palm growth did not reveal trends from only visual examination. However, these were apparent from the maps when using the methods described herein. CSC becomes increasingly lower for 2050 and 2100 indicating a decreasing influence on oil palm growth of future climate. The changes in CSC from CT to 2050 and from CT to 2100 indicate a 3-phase change in the case of both time frames.

The percentage changes in CSC of the original area in CT for each country compared to that in 2050 represent a very large overall increasing trend for the countries from east Brazil to Paraguay which is the first phase of the longitudinal trend and is a very significant observation. Clearly oil palm from, for example, east Brazil could find refuge in French Guiana, Suriname, Guyana and Paraguay. Equally, the sharp decrease from Paraguay to Venezuela represented a very large overall decrease in change of CSC and is the second phase of the longitudinal trend and is another very significant observation. For example, oil palm in Venezuela could find refuges in west Bolivia and Paraguay. An increase in change of CSC was determined through Colombia until Ecuador towards the west of South America represents the third key phase of the longitudinal trend. Also, a three-phased trend was observed from (a) east Brazil to Paraguay, (b) Paraguay to west Brazil and (c) west Brazil to Ecuador in 2100.

The largest effects of climate change were observed for increases of CSC in Paraguay which are remarkable as no other country demonstrated this phenomenon. On the other hand, Venezuela by 2050 and west Brazil by 2100 showed very high decreases. The values for east Brazil were somewhat atypical because large parts of this area are not tropical rainforest and have unsuitable climate for growing oil palm [17]. East Brazil has a high proportion of tropical grassland, desert and dry shrub compared to the other region and countries (https://geography.name/latin-america-climate-and-vegetation/ accessed 25 August, 2020). The mortality of oil palm also tends to increase in the centre of South America and less so towards the coasts, although Paraguay is an exception to this observation. The mortality is very high by 2100 in all countries except for Paraguay and is unsustainable in the high mortality countries.

The changes in CSC are in phases rather than in a direct longitudinal progression from coast to coast. There was a (i) first phase of increasing suitability from east Brazil to Paraguay, (ii) second decreasing phase from Paraguay to Venezuela or west Brazil and (iii) third phase from Venezuela or west Brazil to Ecuador. Hence, refuges may be found generally towards the centre of South America for the eastern and western countries. Colombian oil palm may find refuges in Peru and Ecuador and no countries would find refuges in Venezuela. Oil palm may naturally spread to these refuges through dispersal of seeds and could be enhanced by human intervention. Interestingly increasing, west to east trends in suitable climate for growing oil palm in Africa were reported [3].

Any future plantations may usefully be developed in these potential refuge countries although environmental concerns of deforestation and forest burning must be avoided before any development occurs, irrespective of potential commercial interests given the current climate emergency. Bernal et al., [11] discussed the management of palms in South America, although did not include *E. guineensis*, despite palm oil being heavily traded internationally like some of the other products mentioned in [11]. The general effects of climate change on oil palm mentioned here will also apply to other palms in South America where the effects require managing [25]. The development of plantations towards French Guiana, Suriname, Peru and Paraguay, which may have more suitable climates in the future, is a method for managing oil palms. Other management methods include using leguminous crops, empty oil palm bunches, earthworms, arbuscular mycorrhizal fungi and biochar to protect oil palm against climate change and disease [25]. The development of oil palm resistant to detrimental climates are desirable although it is impossible to know what these novel climates will be a priori and resources may be expended in developing modified oil palm that cannot resist the actual future climate. Finally, managers need to be fully involved in policy making in countries that favour reducing climate change such as those described in the Paris climate agreements which may involve developing renewable energy and avoiding deforestation.

Conclusions

Future climate will have a profoundly negative effect on the ability to grow oil palm in South America. However, there appears to be a three phased longitudinal trend in terms of climate suitability which could be exploited. French Guiana and Surname may provide refuge for oil palm in the future, although these countries are small compared to Brazil, for example, and may have limited scope to create a large industry. Paraguay could be a refuge. Regions such as Venezuela and west Brazil appear particularly susceptible to high reduction in suitable climates. The patterns of change are different from those in Africa. There may be scope for amelioration of the effects of climate change on oil palm [25] and cooperation with the countries actively involved in promoting the actions in the Paris climate agreement should be sought as the most likely means to reduce detrimental climate change.

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