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Research Article

Gearing Present Oil Palm (*Elaeis guineensis* Jacq.) Agroecosystems in the Soconusco, Mexico Towards Sustainable and Good Agricultural Practices

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Abstract

Dialectic interactions between the Sustainable Development Goals (SDG´s), the 2030 Agenda, planetary boundaries (PB) and good agricultural practices (GAP) in agroecosystems with oil palm have rarely been discussed. The main goal of this publication is analyzing reflections and realities about interactions between the 17 SDGs, the 2030 Agenda, nine PB and GAP in agroecosystems with oil palm. The methodological approach included the results of the different field practices during the First International Course of agroecological oil palm production in the Soconusco and consisted of a documentary analysis and focus group discussions. This offered possibilities to analyze qualitative and participative results of the traffic light system methodology (TLSM) and its key issues. The area of oil palm growing in the Soconusco and Istmo-Costa covers 4.37 % and was planted without burning of forestland. The SDG´s that are most strengthened with correct and timely management of the 13 key issues of TLSM, are: SDG2 (Zero Hunger), SDG3 (Good Health), SDG15 (Life on Earth), SDG6 (Clean Water and Sanitation), SDG13 (Climate Action) and SDG1 (Ending Poverty), being addressed in 100%, 69%, 69%, 54%, 54% and 31% of the key issues of the TLSM, respectively. Five PB reflect the realities in the Soconusco. For the biosphere integrity in the oil palm agroecosystems of the Soconusco, the oil palm stands out with growth recordings up to 10 m eco-height and 100000 m^3/ha eco-volume, outperforming the annual oil crops sunflower, rapeseed and soybean. Similarly, oil palm dominates the three annual crops for their respective Eco-capacity, decreasing from 41.54 for oil palm down to 0.3 for soybean. The biochemical flow in the oil palm agroecosystems of the Soconusco reveals that the extraction of N from the soil to produce one ton of palm oil is 47 kg, which is 110.6%, 104.3% and 570% lower than that extracted to produce one ton oil of rapeseed, sunflower and soybean, respectively. Additionally, one ton of palm oil extracts 8 kg of P from the soil, which is lesser than that extracted to produce one ton oil from rapeseed, sunflower and soybean. In all intercropping agroecosystems simulations in the Soconusco based on oil palm the most representative indicators of the combined intercrop assortment, are eco-capacity and/or recycling indices as e.g. the K-Olson index of total yearly litter fall. Eco-volume remains a major yardstick for monitoring the partial fulfillment of the five most relevant PB.

Keywords

Oil palm Agroecosystems in Soconusco, Planetary Boundaries, SDG´s, GAP, TLSM, Biosphere Integrity, Biochemical Flows, Climate Change, Land-System Change, Freshwater Use, Eco-Volume

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1. Introduction

The management of agroecosystems with oil palm is an extremely important field and is under the scrutiny of public opinion. There are very controversial positions and discussions [1-4]. On the one hand, small and large producers who practice the sustainability of their crops in the value-added chain, and on the other hand, the well-meant movements for defending tropical forests, to the point of demonizing oil palm for its style of cultivation and agro-industrial processing, eventually leading into deforestation and destruction of fauna and flora.

Worldwide there are currently 28.9 million hectares cultivated with oil palm, producing 77.2 million tons of palm oil representing 32% of the total world production of vegetable oils [5, 6]. The palm oil production situation is well characterized by the paradox "Development miracle or environmental disaster". These two polarizing opinions have been formed at the international level whereby unfortunately controversial myths happen to be dispelled about the cultivation of oil palm.

Among the 17 most commercialized vegetable oil crops in the international market, oil palm is the leader [7]. Compared to the other predominant oilseed crops such as soybean, rapeseed, and sunflower, this crop has rapidly increased its area, yield, and fresh fruit bunches (FFB) production (Table 1).

Table 1. *Cropping area (ha) and production of oil palm and the most important oilseeds in the world [5].*

Crops	Items	1975	2000	2021
	Area (ha)	3.539.154	10.395.173	28.909.789
Oil palm	FFB t	20.971.418	120.870.856	416.396.560
	Area (ha)	38.764.952	74.307.776	129.523.964
Soybean	Seeds t	64.248.541	161.308.383	371.693.592
	Area (ha)	9.911.404	26.315.945	36.773.580
Rapeseed	Seeds t	8.788.214	40.203.373	71.333.434
	Area (ha)	9.245.951	21.160.524	29.531.998
Sunflower	Seeds t	9.873.560	26.549.692	58.185.633

Especially, its high yield in tons of fresh fruit bunches (FFB) and its respectable crude oil content (20 to 25%), guarantees an oil productivity per hectare that is unattainable for other oil crops [1, 8, 9]. It is a reality that, worldwide, oil palm occupies the smallest area and in one hectare it produces five times more vegetable oil than soybean, six times more than rapeseed and five times more oil than sunflower.

Additionally, palm kernel oil production per hectare is similar to that of soybeans and is twice as high then coconuts and olive trees (Table 2). What ́s more, relations between the oil yield and the water consumption per liter of the different crops are critical. Indeed, the efficient water consumption of oil palm is only 1098 per liter oil ($m^3 t^{-1}$), which is half that of rapeseed and soybean, a third of sunflower and a tenth of sesame (Table 2).

Table 2. *Oil crops and their yield parameters, water consumption and $co_{2eq.}$ emission.*

Crop	Oil yield ($t\ ha^{-1}$) [10]	World oil production in million t in 2022/2023 [11]	Water consumption per liter oil ($m^3\ t^{-1}$) [12]	kg $CO_{2eq.}$ emission MJ^{-1} [13]
Oil palm	2.94	77.22	1098	1.2
Palm nuts and kernels	0.45	8.83	2868	-
Sunflower seeds	0.74	20.36	3366	1.0
Rape or canola	0.72	31.80	2271	1.2
Soybean	0.46	61.49	2145	1.3
Olive tree	0.26	2.82	3015	-
Coconut palm	0.23	3.59	2687	-
Seed cotton	0.13	5.52	4029	1.2
Sesame	0.07	3.5	9371	-

The relationship of CO_2 eq. emissions are used to highlighting the effects of climate change. In the case of oil crops a significant comparison is difficult about their different life and production cycles and the lack of comparable analysis methods. Table 2 shows that the amount of greenhouse gases is very similar between the different crops. However, the different technological levels for the establishment of oil crops and the lack of a standard methodology for comparison make it difficult to determine the contribution of oil palm cultivation to global warming with much accuracy. These methodologies quantify emissions in kg CO2eq. per MJ^{-1}, but do not include CO_2 fixation by oil palm plantations as well as soil organic carbon sequestration.

The main goal of this publication is delivering and analyzing reflections and realities about interactions between the Sustainable Development Goals (SDGs), the 2030 Agenda, planetary boundaries (PB) and good agricultural practices (GAP) in agroecosystems with oil palm. Hence, it requires to combine the nine planetary boundaries with the 17 SDGs.

The ideas and inspirations for these important highlights are the outcome of seminars and field practices realized in the First International Course of agroecological oil palm production during May and July of 2023 in Chiapas, Mexico [14].

Emphasis was made on analyzing the interactions between the main topics and identifying potential synergisms. Accordingly, identify the best way forward to manage multipurpose oil palm growing systems under good agricultural practices whilst pursuing more efficient consumption of limited resources. This is based on the four major driving forces of plant growth (CO_2, water, nutrients, and energy). Very recently it has been published that increasing atmospheric concentrations of carbon dioxide do not threaten people's food security, but will increase the need of cultivated plants for adequate nutrition and more efficient use of water and additionally, will be beneficial for life on earth [15]. Finally, the great diversity of flora and fauna in oil palm ecosystems awaits a much more coordinated application by all the cultivation units.

This implies

1. the characterization of climate-smart and socially equitable production [16];
2. the presentation of several concepts and ideas for the continuous monitoring of oil palm production value chains [17-19];
3. the demonstration of both the life cycle and the carbon footprint of the palm oil value chains and last but not least.
4. the important tools enabling the improvement of the turnover for all driving forces behind any “Green Deal”.

2. Methodology

The idea for this study was born together with the preparation of the different cluster and sessions for the “Diplomado Internacional de producción agroecológica de la palma de aceite en el Soconusco, Chiapas, México”.

2.1. Site Description

The Chiapas State is located in the south of Mexico bordering with Guatemala and is divided into XV economic regions The regions IX-Istmo-Costa and X-Soconusco are located on the Pacific coast. The Soconusco region is formed by the municipalities Acacoyagua, Acapetahua, Cacahoatán, Escuintla, Frontera Hidalgo, Huehuetán, Huixtla, Mazatán, Metapa, Suchiate, Tapachula, Tuxtla Chico, Tuzantán, Unión Juárez and Villa Comaltitlán and the Istmo-Costa region is integrated by Arriaga, Mapastepec, Pijijiapan, Tonalá (Figure 1).

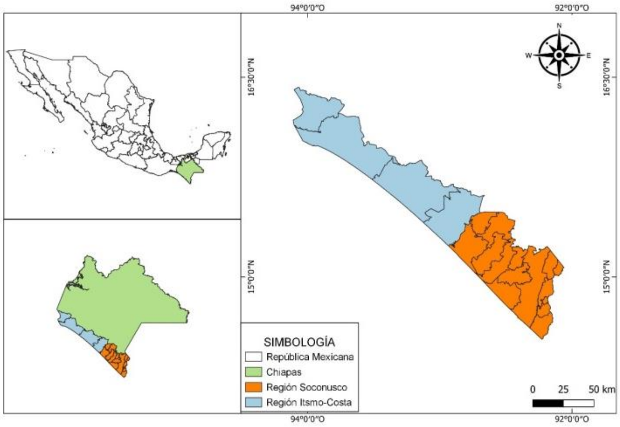

Figure 1. *Map of Mexico, Chiapas, and the position of the Soconusco, Chiapas.*

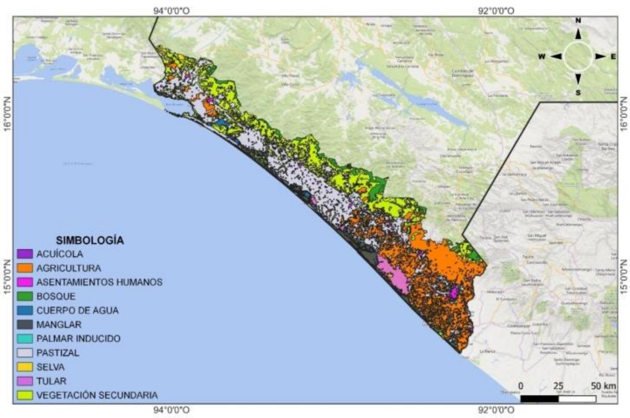

Figure 2. *Map with the different land uses in the Soconusco, Chiapas; Mexico.*

The Soconusco is the southernmost region in the state of Chiapas, Mexico and is bordered by the Pacific Ocean in the west for 145 km, with the Istmo-Costa region continuing further north along the coast. The Sierra Madre de Chiapas extends to the northeast with the Frailesca and Sierra regions, and the eastern border with Guatemala is formed by the Suchiate River. The coastal strip is characterized by mangrove forests, swampy bushland, popales and agricultural areas (Figure 2). The 20 to 45 km wide, flat Pacific coastal strip with an altitude of 5 to 50 m above sea level is followed by rapidly rising hills with a width of 10 to 30 km. The final edge is formed by a chain of volcanoes at an altitude of 2500 to 4000 m above sea level [20]. The highly variable geographical conditions in the Soconusco have a significant influence on the climatic and edafo ecological conditions in a small area.

2.2. Agricultural History of the Soconusco

The excellent conditions in the Soconusco plains have provoked several waves of monoculture cultivation over the last 80 years. These were always preceded by extensive land acquisitions through slash-and-burn farming. The cultivation of fruit bananas (variety Gros Michel) between 1950 and 1965 was followed by cotton cultivation (1970 to 1987), which in turn was drastically replaced on some of these areas by soybeans, sesame and sorghum and on the other part by mango (variety Ataúlfo) and fruit bananas (variety Enano Gigante) in the mid-1980s [21].

In total, the Soconusco has an area of 464,400 hectares, which corresponds to 6.33 % of the state of Chiapas. Around 400,000 hectares of this are currently used for agriculture and forestry [22, 23]. The most important crops are coffee (*Coffea arabica* and *Coffea canephora*) on 65,414 hectares, corn (30,029 hectares), oil palm (32,044 ha), sugar cane (14,255 hectares) and soybeans (12,934 hectares). Fruits are grown on 48,818 hectares. The most important crops are mango (32,128 hectares), bananas (8,905 hectares), plantains (5,045 hectares), papaya (1,401hectares) and rambutan (849 hectares). Cocoa grow on 8,501 hectares and coconut palm grow in many coastal areas widespread [23]. Despite good location conditions, agriculture in the Soconusco presents the typical situation for Mexico's backward south. The importance of exports and supply to the northern domestic market allowed, on the one hand, a mechanized, intensive large-scale cultivation of cash crops to flourish, but on the other hand could not curb the subsistence economy of annual crops based on slash-and-burn agriculture in the most populous region of Chiapas.

Today, referring to the production and area of oil palm, the Soconusco is considered by the producing municipalities of the Chiapas Coast, which integrates the regions Soconusco and Istmo-Costa (Table 3).

Table 3. Structure of land uses (ha) and other productivity income from the oil palm growers in the regions IX Istmo-Costa and X Soconusco, Chiapas; Mexico [24-26].

Municipalities with oil palm	Oil palm area (ha)	Cropping area (ha)	Preserving areas (mangrove, swamps, natural forests, popal)	Pasture (ha)	Aquaculture (ha)
Acacoyagua	442.21	3,253.45	15,843.11	5,367.14	0
Acapetahua	11,699.28	17,843.61	15,968.76	19,333.22	0
Escuintla	669.72	8,805.21	19,832.64	12,551.67	0
Frontera Hidalgo	76.91	8,004.72	400.35	771.12	0
Huehuetán	2,275.13	20,664.72	1,406.46	7,696.05	0
Huixtla	346.08	24,084.55	11,514.28	2,950.49	0
Mapastepec	9,215.87	12,981.76	51,725.23	54,697.10	47.138
Mazatán	214.70	22,083.60	11,056.72	3,990.20	0
Pijijiapan	2,412.92	3,206.66	85,018.07	84,180.55	299.859
Suchiate	121.77	14,483.06	3,057.44	47,24.21	0
Tapachula	1,131.15	67,383.11	116,88.23	12,944.84	71.636
Tuzantán	35.25	14,057.27	0	2,971.12	0
Villa de Comaltitlan	3,403.08	20,940.97	13,448.39	9,139.31	0
Total	32,044.04	237,792.77	240,959.76	221,317.08	418.63

2.3. The Traffic Light System Methodology

The good agricultural practices (GAP), managed using a traffic light system (TLS), have been developed with and for smallholder growers and farmers in oil palm, coffee, cacao, tea, pineapple and different annual tropical crops [27]. The TLS not only steers the management control points, but also allows information to be collected on whether growers execute the recommended actions and on the quality of oil palm produced. The TLS is thus an excellent system for disseminating recommended practices and validating their effectiveness in a continuous improvement process. The TLS system is a virtuous circle in which feedback on its use and recognition by stakeholders of its effectiveness refines the system in identifying those practices which are optimal for producing the defined crop in sustainability manner. The experiences of the GAP and TLS approaches was used to create up the traffic light system methodology (TLSM). In descending order, the SDGs that are most strengthened with correct and timely management of the 13 key issues that make up TLSM. This will be manage the GAP in agroecosystems with oil palm with ethics, social, environmental, business and professional responsibility is achieved in two major challenges as follows:

1. to adapt practices and management strategies to obtain and maintain high yields of RFF and oil content in areas where oil palms is currently grown.
2. to develop practices for new oil palm growing areas that will become similar to current oil palm growing areas as a result of climate change, but which do not have a traditional oil palm culture to build on.

2.4. Methodological Approach, Scope and Design

The methodological approach included the strategy to use the results of the different realized field practices during the First International Course of agroecological oil palm production. This gave the possibility to analyze qualitative and participative results of the TSLM key issues and quantitative estimating of the sustainability tools and the Eco-capacity.

The qualitative methodological perspective consisted of documentary analysis and focus group discussions. Four focus group discussions were held with the 42 farmers who participated in the international course on agroecological oil palm management held at the Autonomous University of Chiapas.

The scope of the quantitative approach was exploratory through estimating the furthering of Eco-capacity, photosynthetic efficiency, dew potential and cooling potential and henceforth the reduction of energy dissipation and input losses.

2.5. Sustainability Tools and the Eco-capacity

Addressing the sustainability tools implies the furthering of Eco-capacity, photosynthetic efficiency, dew potential and cooling potential and henceforth the reduction of energy dissipation, input losses and above all optimizing the green deal turnover.

The eco-capacity C_{eco} of plant biotope is defined by Corley & Tinker 2015 [28] as:

C_{eco} = R_{esi} x $V_{eco\text{-}actual}$ = resilience index x actual eco-volume

Where R_{esi} = Resilience index = $V_{eco\text{-}actual}$ x $V_{bio}/V_{eco\text{-}max}$

V_{bio} = H_{eco} x BA_{soil} and where $V_{eco\text{-}max}$ = V_{eco} at climax stage nearby forest

H_{eco} = weighted plant height per unit of surface (usually ha)

BA_{soil} = sum Basal area plant stem at soil level /unit of surface (usually ha).

Finally, the Fortaleza plant ideotype will help simulating an important parameter, eco-capacity, describing overall environmental status of a plant community based on easily measurable spatial parameters [29]. Eco-capacity loss represents the potential biotope regression. For the sake of prospective development let us assume that 3.5% of permanent crops from agricultural land (= 36,8 % from total land) would be uplifted to 15% this would be an enormous increment from 2-25 Ceco/ha up to 110 which will boost total Ceco units tenfold up to 11,5% x 110 = 1265/permanent crops instead of 11,5 % x (2+25)/2 = 155 Ceco units / pastures and seasonal crops.

3. Results and Discussion

3.1. Gearing Sustainable Oil Palm Within the Soconusco Monoculture Cropland

The recorded data from the Soconusco crop area are submitted to four appraisal systems: (I) the ordinary spatial agricultural parameters, (ii) the U.N.-Sustainable Development Goals, (iii) the Traffic Light System Methodology, and finally to (iv) the planetary boundaries. This phenomenological challenge is compounded by the practical need to integrate the most important development drivers.

The larger part of the Soconusco cropland area (85.37%) is devoted to monoculture, albeit mainly perennial of nature. Fortunately, not more than 1/4 are cropped with annual/seasonal crops against 3/4 perennial crops.

The Soconusco oil palm agroecosystems grow from South to North along the pacific coast and the hills in a mosaic stripe with five to seventeen kilometres width. Left side embedded by preserving areas like mangroves, swamps, and natural forests and popal. Right side exist mostly pastures, fruit orchards and annual crops. This oil palm area covers 4.37 % (Table 3) of the total land area of the Soconusco and Istmo-Costa region.

3.2. Key Issues of the Traffic Light System Methodology and the U.N. Sustainable Development Goals

The United Nations approved in 2015 a total of 17 SDGs (Sustainable Development Goals) [30]. Eleven of them are addressed, directly (1), in different key issues of the GAP for the diagnosis, monitoring and evaluation of good agricultural practices (GAP) in agroecosystems with oil palm, through the traffic light system methodology (TLSM), which represent 65% of the total SDGs (Table 4). SDG 17 is addressed indirectly (±), which consists of "strengthening the means of implementation and revitalizing the global partnership for sustainable development". Managers, technicians, producers, and/or associated or individual oil palm farmers must establish strategic alliances, whose purposes consist of the agroecological reconversion of agroecosystems with oil palm [31-33]. and the realization of the transformative vision towards economic, social and environmental sustainability of the 2030 Agenda, which would be the action plan in favor of people (producers or farmers, agricultural collaborators, etc.), territorial development and the prosperity of the communities where the agroecosystems with oil palm are located.

In descending order, the SDGs that are most strengthened with correct and timely management of the 13 key issues that make up the TLSM, - in order to achieve the desired GAP goals in the oil palm agroecosystems with ethics, social, environmental, business and professional responsibility -,: SDG2 (Zero Hunger), SDG3 (Good Health), SDG15 (Life on Earth), SDG6 (Clean Water and Sanitation), SDG13 (Climate Action) and SDG1 (Ending Poverty), which are promoted in 100%, 69%, 69%, 54%, 54% and 31% of the pillars of the TLSM, respectively (Table 4). SDG4 (Quality Education), SDG7 (Affordable and Sustainable Energy), SDG8 (Decent Work and Economic Growth), SDG9 (Industry, Innovation and Infrastructure) and SDG12 (Responsible Consumption and Production) are addressed in a pillar of the TLSM, which accounts for 8% of these (Table 4).

Only five SDGs are not addressed by the key issues of the TLSM in agroecosystems with oil palm, representing 29.4% of the SDGs. These are: SDG5 (Gender Equality), SDG10 (Reducing Inequalities), SDG11 (Sustainable Cities and Communities), SDG14 (Marine Life) and SDG16 (Peace, Justice and Strong Institutions) because they need to be addressed in the policies of oil palm companies and municipal governments to integrate them as good management practices.

In order of importance, the key issues of the TLSM that contribute to the realization of different SDGs correspond to the key issues number 10 (Irrigation, water footprint, drainage, agroforestry systems and diversification), six (Management of the oil palm systems and their associated crops), one (Site selection, plot history, mapping, data recording by plots of the agroecosystem), four (Nursery practices and quality of the plants), seven (Weed management), 13 (Social and human rights, Social and Corporate Responsibility (CSR) and compliance, social care, training and coaching, social and labor security, agricultural and accounting records), eight (Nutrition management), nine (Integrated pest and disease management) and 11 (Management of the sanitation pruning and cleaning of the oil palm trees). These nine key issues participate into four to seven SDGs. Only key issue two (Seed and cultivars origin) contributes to the realization of a single SDG. The remaining three key issues three (Nursery practices and quality of the plants), five (Transplanting systems of the oil palm and systems with mixed and intercropping crops) and 12 (Harvest and transportation management of the FFB) of the TLSM encourage the realization of two to three SDGs. (Table 4).

Table 4. *Relationships between the different key issues that make up the traffic light system methodology (TLSM) with the 17 SDGs that are integrated into the 2030 agenda.*

Number of key issues of the TLSM	**Sustainable Development Goals (SDGs)**																	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Total**
1	0	1	1	0	0	0	0	0	1	0	0	-	1	0	1	0	±	5
2	0	1	0	0	0	0	0	0	0	0	0	-	0	0	-	0	±	1
3	0	1	0	0	0	1	0	0	0	0	0	-	1	0	-	0	±	3
4	0	1	1	0	0	1	0	0	0	0	0	-	1	0	1	0	±	5
5	1	1	0	0	0	0	0	0	0	0	0	-	0	0	1	0	±	3
6	1	1	1	0	0	1	0	0	0	0	0	-	1	0	1	0	±	6
7	0	1	1	0	0	1	0	0	0	0	0	-	1	0	1	0	±	5
8	0	1	1	0	0	1	0	0	0	0	0	-	0	0	1	0	±	4
9	0	1	1	0	0	1	0	0	0	0	0	-	0	0	1	0	±	4
10	1	1	1	0	0	1	1	0	0	0	0	-	1	0	1	0	±	7
11	0	1	1	0	0	0	0	0	0	0	0	-	1	0	1	0	±	4
12	1	1	0	0	0	0	0	0	0	0	0	-	0	0	-	0	±	2
13	0	1	1	1	0	0	0	1	0	0	0	1	0	0	-	0	±	5
Total	4	13	9	1	0	7	1	1	1	0	0	1	7	0	9	0	13	
Percentage	31	100	69	8	0	54	8	8	8	0	0	8	54	0	69	0	100	

0: not addressed, 1: addressed directly, ± addressed indirectly

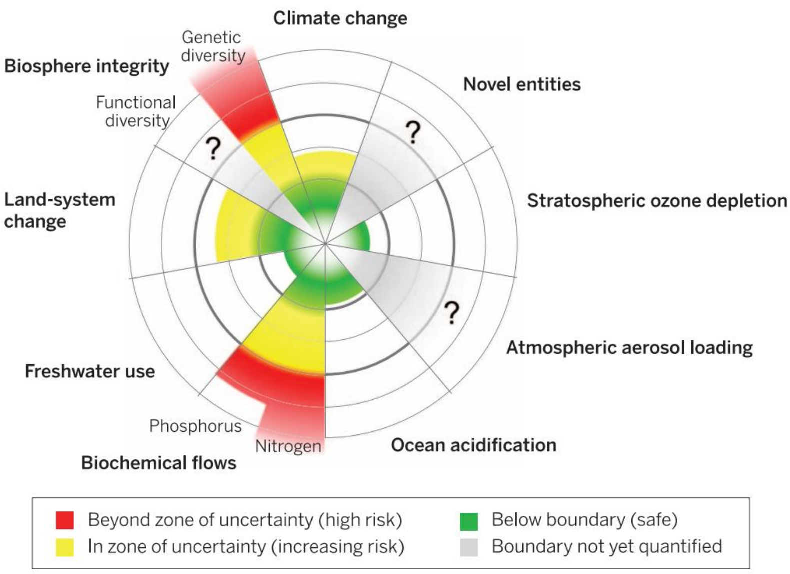

Figure 3. *Planetary boundaries and their real situation [35].*

Figure 3 illustrates the planetary boundaries and their real situation of which five of them are related to agricultural activities or to the chain of production, marketing, and consumption of quality, healthy, safe and traceable food [34]. These five planetary boundaries are: the biosphere integrity (red), biochemical flows (red), climate change (yellow), land-system change (yellow), and freshwater use (green) (Table 5).

Table 5. *Relationship of planetary boundaries associated with the expansion of oil palm cultivation.*

Planetary boundaries	Zone	Effects of the expansion of oil palm production
Biosphere integrity is related to the loss of diversity = Loss of functional diversity and genetic diversity (Terrestrial and marine).	High risk Red = past the boundaries	Ecological footprint = Environmental impacts: deforestation, damage to protected areas or riverbeds, the exponential increase in soil erosion, the contribution of sediments to rivers and a serious impact on the landscape.
Biochemical flows are related to the biogeochemical cycles of nitrogen and phosphorus = interferences in the global nitrogen and phosphorus cycles	High risk Red = past the boundaries	N:P:K:Ca:Mg per hectare ratios and opportunities to contaminate soil and water in the watershed where oil palm agroecosystems are located and the oceans.
Climate change is linked to the climate crisis.	Increasing risk Orange, with danger of passing to high risk	Carbon footprint = Greenhouse gases (GHG).
Land-system change It manifests itself in deforestation and other land-use changes in boreal, temperate, and tropical forests.	Increasing risk Orange, with danger of passing to high risk	Poor biodiversity of fauna and flora in oil palm plantations. Deterioration of ecosystems. More greenhouse gas emissions.
Freshwater use is related to global consumption and unsustainable use of freshwater = water cycle.	Safe Pale green, prudence so as not to go to increasing risk zone	Water footprint = Survival of fish and aquifer fauna in drainage channels and channels. Surface and groundwater contamination

From the point of combining the analyses of SDGs with the key issues of the TLSM, this exercise is only meaningful in so far all impacts do fit into the five corresponding main focusses of the planetary boundaries.

3.3. The Biosphere Integrity in the Oil Palm Agroecosystems of the Soconusco

The biosphere integrity represents a high-risk zone, which could provoke loss of functional diversity and genetic diversity (Figure 3). In Indonesia and Malaysia, the massive expansion of oil palm growing, based into the deforestation of millions of hectares of primary and secondary forest caused pollution and reduced biodiversity [36, 37]. By contrast, in Latin America, 79% of the expansion of oil palm cultivation has taken place in areas of pasture, cropland and banana crops. Only in Petén, Guatemala and the Amazon, deforestation has been done to establish new plantations with oil palm, which represents 21%.

In the literature, claims are reported that extensive oil palm plantations with *Elaeis guineensis* Jacq. do not replace tropical forests, support few species of conservation importance, and affect the biodiversity of adjacent habitats through fragmentation, edge effects, and pollution [38]. However, there is agreement that there is enough non-forested land for plantation development to allow large increases in production without further deforestation, demonstrating that the impacts of oil palm depend on the model under which its expansion is promoted, rather than on the characteristics of the crop itself [39].

Oil palm dominates with 10 m eco-height and 100000 m^3/ha eco-volume all three annual crops viz. sunflower (V_{eco} 18000 m^3), rapeseed (13000 m^3) and soybean (8000 m^3). Similarly, oil palm is also dominating the three annual crops for their respective Eco-capacity, decreasing from 41.54 for oil palm down to 0,3 for soybean, 138 times less (Table 6).

Table 6. *Comparison of different eco parameters between the main oil crops.*

Item (u/ t oil	Soybean	Sunflower	Rapeseed	Oil palm
Bio-volume Vbio (m^3 ha^{-1})	18.85	176.62	122.46	296.73
Eco-volume (m^3/ha)	8.000	18.000	13.000	100.000
Eco-capacity (Ceco)	0.30	26.49	6.37	41.54
ELSTON Multiplicative Index*	238661923,5	5806080,0	3970058,4	33088,0
ELSTON/Ceco unit	795539745,0	219180,1	623243,1	796,5
Inefficiency wrt oil palm***	998752,4	275,2	782,4	1,0

* Multiplicative Index ELSTON is free of units; ** Corley & Tinker 2015; *** Fortaleza model

From the agroecological perspective, one of the aspects to be considered for the expansion of oil palm in Latin America is the redesign of agroecosystems, so that they are complex or very complex in structure, which is described in chapter V of the manual for oil palm producers in Mexico. The agronomic management of these agroecosystems with a heterogeneous and complex structure must be documented through a chronological record to determine their benefits to the soil, water, biodiversity inside and outside the agroecosystem and ecosystem services. This is possible with the TLSM because the ecological footprint (EFP) indicator only measures the anthropogenic impact on the environment, but it does not evaluate the associations, relationships and ecosystem functions that occur in agroecosystems with complex or very complex structure, which are multifunctional, more efficient and stable, resilient, productive and less dependent on external inputs.

3.4. The Biochemical Flows into the Oil Palm Ecosystems

The biochemical flows are also located in the high-risk zone (Figure 3). The planetary boundary regarding biochemical flows is associated with water pollution by indiscriminate applications of synthetic fertilizers containing nitrogen (N) and phosphorus (P) for food production. This includes also the lifecycle of oil palm ecosystems and their impacts into water and energy fluxes [40, 41]. A part of the biogeochemical cycles of the N and P occurs in agroecosystems, which demands agroecological management of the non-renewable natural resource soil, which includes soil and water conservation practices, nourishing plant productive biodiversity based on the principles of the 4R and feeding the soil with the 5M principles of sustainability dynamics [42]. These last principles lie in permanently providing the soil with organic matter (M1), promoting the proliferation of beneficial microorganisms (M2), applying organic fertilizers enriched with flour minerals (M3) of rock, applying biological molecules (M4) through bio ferments and encouraging the farmer opening his mind (M5) to the change in the production scenario.

Oil palm agroecosystems need not more than, 2 kg of pesticides or herbicides to produce 1000 kg of oil palm (Table 7), which is 550% less than that applied to oilseed rape; 1400% and 1450% less than that sprayed in sunflower and soybean agroecosystems, respectively. This shows that good management of key issue seven (Weed management) and nine (Pest and disease management) of the TLSM can have a minor negative impact on biodiversity loss inside and outside the soil. Other very important aspects for promoting biodiversity within and outside the soil in agroecosystems with oil palm compared to soybean, sunflower and rapeseed are their higher Bio-volume, Eco-volume and Eco-capacity (Table 7).

Table 7. *Comparison of the eco-capacity for the production of 1000 kg of oil between soybean, sunflower, rapeseed and oil palm [28] (data from Corley and Tinker 2015).*

Inputs (u/ t 0il	Soybean	Sunflower	Rapeseed	Oil palm
Nitrogen (N kg)	315	96	99	47
Phosphate (P2O5 kg)	77	72	42	8
Pesticides/herbicides (kg)	29	28	11	2
Others (kg)	117	150	124	88
Energy (GJ)	2,9	0,2	0,7	0,5
Biased SUM of inputs (# units)	540,9	346,2	276,7	145,5

Very recently, among the principles of 5M, bio stimulants are being promoted, which are substances, microorganisms or mixtures of them, which when applied to the soil or to the plants, beneficially stimulate various processes in productive biodiversity: they help them to better absorb and assimilate the nutrients found in the soil, to be more tolerant to various factors such as drought, salinity, cold, heat or to be resistant to organisms that attack and destroy crops, which are caused by fungi, bacteria, viruses, nematodes and others. In addition, bio stimulants improve their agronomic characteristics, obtaining better quality foodstuffs free of agrochemicals and/or pesticides [43, 44]. These bio stimulants can be included in the management of TLSM key issues four (Agro-ecological soil management), eight (Nutrient management) and nine (Pest and disease management). In summary, bio stimulants (Humic and fulvic acids, animal and vegetable protein hydrolysates, algae extracts and botanicals, chitosan and biopolymers, beneficial native micro-organisms and zeolites and rock flours) promote the metabolic activity of soil microbiology and contribute to the quality, health and life extension of oil palm agroecosystems.

This will contribute to the reduction of nitrogen and phosphoric fertilizers through natural bio fertilization, natural bio stimulation of root growth, and natural bioregulation of soil pathogens. This requires urgent training of oil palm farmers in the correct and timely implementation of GAP because are components in the key issues number four, eight, nine and 10 of the TLSM that contribute to improving the quality and soil health of oil palm agroecosystems (Table 4).

It is important to note that the extraction of N from the soil to produce one ton of palm oil is 47 kg (Table 6), which is 110.6%, 104.3% and 570% lower than that extracted to produce one ton of rapeseed, sunflower and soybean oil, respectively. Additionally, one ton of palm oil extracts 8 kg of P from the soil, which is 5.25, 9.0 and 9.6 times less than that extracted to produce one ton of rapeseed, sunflower and soybean oil, respectively. These estimates show that oil palm cultivation contributes less to biochemical flows than rapeseed, sunflower and soybean respectively.

SDG15 (Life on Earth) is inversely related to this planetary boundary because a sustainable management of terrestrial ecosystems (agroecosystems and forests), does not promote desertification, halts and reverses soil degradation, and halts the loss of biodiversity, which will promote the ecosystem services that biodiversity offers to the communities where oil palm agroecosystems are located. Therefore, wise and timely management of nine key issues of the TLSM contributes to mitigating this planetary boundary and to the realization of SDG15 (Table 4).

3.5. The Planetary Boundary Climate Change in Oil Palm Agroecosystems

The planetary boundary of climate change is located in the zone of increasing risk (Figure 3). The cause of climate change is attributed to anthropogenic greenhouse gas emissions (GHGE: CO_2, CH_4, and N_2O). The literature reported consistently substantial effects on oil palm cultivation into extreme weather events, increasing drought and flooding, soil moisture fluctuation, heat stress periods and significantly impacts to the oil palm physiology and life cycles [45-47].

In chapter V of the manual for oil palm producers in Mexico, it is concluded that the Carbon Footprint (CF) indicator is not valid to quantify the quality and health of the oil palm agroecosystem in relation to its contributions to global warming, because it excludes the sequestration of CO_2 by the autotrophic organisms that cohabit in agroecosystems [34]. In addition, the CF varies according to productivity, technological level and cultivation conditions [48], whose results are not comparable because there are different methodological alternatives to quantify it.

In addition, Table 7 shows that to produce one tons of palm oil, a smaller amount of external inputs is used, including N, which, due to the activity of soil microorganisms, can be transformed into N_2O, which is a greenhouse gas. In summary, it can be stated that the production of one ton of palm oil emits less greenhouse gases than that obtained from soybean, sunflower and rapeseed.

To quantify the quality and health of the agroecosystem with oil palm in relation to its contribution (positive or negative) to global warming is a carbon dioxide equivalent (CO_2eq) balance, which can be partial (PB CO_2eq) or total (TB CO_2eq), for which it is necessary to standardize methodological criteria for the estimation of the partial (PB CO_2eq) or total balance (TB CO_2eq) and to be able to establish comparisons between different agroecosystems with oil palm. Another aspect to be considered for the qualitative assessment of agroecosystems with oil palm regarding their contribution to global warming is the comparison of different oil crops with the respective parameter of evaporative cooling.

GAP with 27 agricultural practices and the implementation of circular economy principles have been reported to reduce impacts from climatic events in oil palm plantations [49, 50]. The 13 key issues of the TLSM are associated or related to the 17 SDGs; seven of the key issues of the TLSM promote SDG6 (Clean Water and Sanitation) and seven of them SDG13 (Climate Action).

3.6. The Planetary Boundary Land-System Change in Oil Palm Agroecosystems of the Soconusco

The planetary boundary of land-system change is located in the zone of increasing risk (Figure 3). Oil palm agroecosystems present a great number of opportunities to avoid the oil palm monoculture. Key issue six, management of the oil palm systems and their associated crops, demonstrates how it is possible to prevent, that the component forest felling, monoculture and ecological footprint, which is classified as high danger, is practiced. This evade the cutting of forests or jungles should not continue to increase the agricultural frontier and establish agroecosystems with oil palm.

Especially, the spatial and temporal scales of oil palm agroecosystems need to be recognized and implanted into the land-system change strategies. Sometimes, the expansion of oil palm plantations is carried out in areas that are for other agricultural uses, which is what experts recommend for the humid American tropics because it has great potential for palm growing.

Hence in spite of the large amount of perennial crops, the overall environmental signature of Soconusco cropland is deceiving for all spatial parameters to the point that a negative value i.e. dissipation of 29,36 % of the cooling volume is recorded for the whole Soconusco cropland area. Although oil palm has an eco-volume of 100.000 m^3/ha, the average eco-volume of the whole cropland area is only 36.405 m^3/ha, equivalent to an average eco-height of only 3.6 m. This also means that not only yearly eco-precipitations and dew deposit are low but also litter fall recordings are lower than the yearly export of mineral nutrients through harvesting.

Corn and soybean are important food crops although their environmental impact is rarely positive due to the traditional shifting cultivation (roza, tumba, quema). Both crops have a very poor environmental signature terms of eco-volume (less than 20.000 m^3/ha), eco-capacity (< 400 Ceco/ha), eco-precipitations (<20 mm/y/ha), cooling confinement (> 75% dissipation of the cooling volume) and finally, a poor dew potential of ca. 5 index, even though corn and soybean are included in a same rotation cycle.

Intercropping crop species is an easy way of combining the desired properties of different crops. Mind you, one should not squeeze complemental crops in between existing interrow distances. Adjustment of intrarow distance will eventually allow the desired planting density.

The seasonal/annual crops will of course be part of an adequate rotation cycle between the perennial tree crops (Table 8).

The three major crop belts (*in casu* oil palm) will alternate each 16 m with a companion crop be it cocoa, mango or even with a seasonal intercrop as corn or soya, the whole enclosed between a road of two rows of shade trees like mango, *Melia azedarach* (arbol de paraíso) etc. summing up to:

1. 3 x 16 m = 48 m oil palm
2. 2 x 16 m = 32 m cacao, fruit trees or coco palm, corn etc.
3. 1 x 20 m = 20 m road + shade tree

The three intercrop examples all contain favourable indicator variables, generally more efficient than the average of the major Soconusco crops, except for oil palm and mango (Table 8). You could also construct an intercrop with either banana or sugarcane as a companion crop. If so, please do not double-burn the sugarcane. Experiments in the Soconusco revealed highly significant increases of sugar yield, stove mulch as well as beneficial insects and earth worms [51].

Table 8. *Intercropping options with oil palm covering 48% of area for the Soconusco.*

Cropping system	Ecovolumen (m^3/ha)	Eco-precipitation (mm/y/ha)	Dew potential (Index)	Cooling confinement (%)
Oil palm monoculture	100.000	100	47,7	49,28
Mango orchard	60.000	60	68,73	4,79
Oil palm (48 %) + cocoa (32 %) + mango/shade (20 %)	73.200	73,2	31,30	42,1

Cropping system	Ecovolumen (m^3/ha)	Eco-precipitation (mm/y/ha)	Dew potential (Index)	Cooling confinement (%)
Oil palm (48 %) + corn (32 %) + mango/shade (20 %)	65.072	65,8	25,20	30,4
Oil palm (48 %) + soybean (32 %) + mango/shade (20 %)	63.920	64,4	24,90	30,1

The major crop, in *casu* oil palm, is to be considered as the major engine of the intercrop construct and hence, deserving priority for inputs, mending and maintenance. The companion crop as well as the shade trees will anyhow benefit from the side effects (losses) of the domineering crop. The general rule is to supply tubers and roots, as well as tree-monocots, with K, leguminous crops with P and cereals with N.

Above combination will give an optimum windbreak effect across the different belts, inducing a more stable and humid atmosphere supplying evaporative cooling, eco-precipitations as well as important, although undervalued, dew droplets. The latter phenomena will extend not only the daily growing period but also the number of growing days over time.

When reaching sufficient height it will be possible to combine oil palm with cattle ranching, using small breeds like “Dahomey” or also sheep’s.

3.7. The Freshwater Use in the Oil Palm Agroecosystems of the Soconusco

The only planetary boundary closely related to food production that is located in the safe zone is the freshwater use (Figure 3). This is a renewable natural resource, the pollution of which has serious consequences for human beings, biological diversity, agriculture; and the economy of the producers or farmers, of the locality and that of the country.

The key issue 10 of the TLSM, irrigation, water footprint, drainage, agroforestry systems and diversification, demonstrated how GAP in agroecosystems with oil palm could contribute to an efficient and effective use of this natural resource in the production of FFB with quality, safety and traceability. This allows to quantify the different water footprints (Green, blue and gray) and implement strategies for responsible management of this renewable natural resource.

Oil palm is one of the most water-efficient oil crops (Table 2). Seven of the 13 key issues that make up the TLSM address SDG six (Clean Water and Sanitation), which demonstrates the multidimensionality to verify whether this resource is managed efficiently and effectively in agroecosystems with oil palm.

On this basis, it is urgent to determine new indicators or indices to assess the management of the vital liquid in the agroecosystems with oil palm.

The knowledge of the respective water indicators (Green, Blue and Grey) in the Soconusco can be carried out a more efficient management of this renewable resource for the agroecosystem and the hydrographic basin where oil palm cultivation is developed.

The estimates in Table 7 lead to the assertion that for a lower use of external inputs (Pesticides and herbicides and others) to produce 1000 kg of palm oil the amount of grey water is lower compared to the amount that can be contaminated with soybean, sunflower and rapeseed. Similarly, it can be concluded that the contamination of green and blue water tends to be lower if palm oil production is promoted.

Finally, all intercrop simulations in Table 8 are characterized by better water recycling indicators than the present situation in the cropland area in the Soconusco as e.g.:

1. Eco-volume (recycling of CO2 and water vapor),
2. Eco-capacity (proportional to yearly litter fall, and hence to the organic matter recycling; see Olson = Lt/Ls i.e. total yearly litter fall over soil litter),
3. Eco-precipitations (ca. 10 mm yearly rainfall per meter eco-height).
4. Dew potential (proportional to canopy leaf surface),
5. Cooling volume (cfr evaporative cooling),
6. % cooling confinement (if negative, indicates that part of the cooling volume cannot be confined w/n the eco-volume, eventually resulting in cooling dissipation).

4. Outlook the Way Forward and Beyond

The results of oil palm growing in the Soconusco demonstrate the opportunities and alternatives how should be made, wherever necessary, to transform oil palm cultivation into a successful business activity, with the potential ability to attract younger generations. This is achieved through greater productivity and through sustainable production of oil palm, which meets the standards set by the RSPO (Roundtable on Sustainable Palm Oil), at the same time, meets all the requirements demanded by environmental movements and NGOs.

Both purposes can be achieved with intelligent and correct management of GAP and GPP (Good Postharvest Practices), which includes clean and innovative technologies, respecting international labor standards; in such a way that palm growers work as members of farmers' associations supported by adequate teaching and training in GAP and GPP. This need support of credits, affordable and accessible extension services, which contributes to agroecological management of the agroecosystem for its recarbonization, restore their health, promote biodiversity inside and outside the soil, in addition to promoting biogeochemical cycles in existing oil palm agroecosystems, mainly that of nitrogen, phosphorus and potassium. This means that GAP and GPP must contribute to reducing the carbon footprint, the water footprint, the negative impacts on the environment, promoting biodiversity, therefore, making the Sustainable Development Goals (SDGs) a reality [3, 52, 53].

The knowledge and research gaps to find the way forward and beyond need, to include the following strategies and indicators for the different planetary boundaries, where Eco-volume (Veco) plays a pivotal and integrating role across all five boundaries:

1. Occupy and prove the integrity of oil palm ecosystems for the Soconusco and determine the Ecological footprint.
2. Analyze the Eco-volume and eco-capacity like railway station for the determination of the indicators: Eco-capacity = Ri (Resilience index) x Veco (Eco-volume) where Resilience index (Ri) = Bio-volume (Vbio)/Veco-max. Ceco tells us in how far the present agro-climax (in casu oil palm) is mimicking the original eco-climax.
3. Optimize the key issues Agro-ecological soil management, Weed management, Nutrient management and Pest and disease management for the different site conditions and determinate verifiable indicators.
4. Use the Indicator: K-Olson = Lt/Ls = total yearly litter-fall/soil litter per hectare as a measure of organic recycling and to quantify the colony-forming units per gram of soil of the functional groups of the genera of microorganisms involved in the decomposition of organic matter and in the biogeochemical cycles of nitrogen and phosphorus that occur in agroecosystems with oil palm.
5. Examine and validate the impacts of oil palm growing to different climate change parameters. These indicators are Eco-precipitations (Peco) in mm/year = 10 mm of yearly rain per m eco-height; Evaporative cooling and Condensation potential cfr Dew potential. These three indicators are all contributing to the recycling of water. Additionally, the carbon dioxide equivalent balance must be estimated between that which is emitted into the atmosphere versus that which is fixed inside and outside the soil.
6. Elaborate and verify opportunities for different oil palm systems.
7. Analyze the Cooling confinement in % = (Veco - Vcool)/Vcool x 100 as a contrary measure of cooling dissipation.
8. Determine the freshwater use for oil palm growing and oil palm processing.
9. Compare the water efficiency to produce one ton oil in oil palm monoculture and in intercropping systems by the indicator rain water use efficiency.

5. Conclusions

Our research presents results of the field practices realized during the First International Course of agroecological oil palm production in the Soconusco, consists of documentary analyses and focus group discussions with farmers, researchers and state employees. Main goal was to characterize the sustainable development of oil palm agroecosystems through the integration of the 2030 Agenda, the planetary boundaries and the good agricultural practices in the Soconusco, Mexico. This offered possibilities to analyze qualitative and participative results of TLSM and its key issues. Especially, were analyzed the interactions and impacts between the GAP practices and the five relevant boundaries: (i) the biosphere integrity in the oil palm agroecosystems of the Soconusco, (ii) the biochemical flows into the oil palm ecosystems, (iii) climate change in oil palm agroecosystems, (iv) land-system change in oil palm agroecosystems and (v) the freshwater use in in the oil palm agroecosystems of the Soconusco. The outlook presents main priorities and necessary solutions for future "Research and Development" concurring to the implementation of sustainable oil palm agroecosystems.

Abbreviations

CF	Carbon Footprint
EFP	Ecological Footprint
FAO	Food and Agriculture Organization
FFB	Fresh Fruit Bunches
FONAP	Das Forum Nachhaltiges Palmöl
GAP	Good Agricultural Practices
GHG	Greenhouse Gases
GHGE	Greenhouse Gas Emissions
GPP	Good Postharvest Practices
GREPALMA	Gremial de Palmicultores de Guatemala
MPT	Ministério Público do Trabalho
NGOs	Non-Governmental Organizations
OIT	Organização Internacional do Trabalho
PB	Planetary Boundaries
RSPO	Roundtable on Sustainable Palm Oil
SDG´s	Sustainable Development Goals
SIAP	Servicio de Información Agroalimentaria y Pesquera
TLS	Traffic Light System
TLSM	Traffic Light System Methodology

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Conflicts of Interest

The authors declare no conflicts of interest.

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