agriculture

Article

Zoning of Potential Areas for the Production of Oleaginous Species in Colombia under Agroforestry Systems

Luisa F. Lozano-Castellanos [1,2,*], José E. Méndez-Vanegas [3,4], Francisco Tomatis [1], Adriana Correa-Guimaraes [1] and Luis Manuel Navas-Gracia [1,*]

1 TADRUS Research Group, Department of Agricultural and Forestry Engineering, University of Valladolid, 34004 Palencia, Spain
2 Research Group on Biodiversity and Dynamics of Tropical Ecosystems GIBDET—Faculty of Engineering Forestry, University of Tolima, Ibagué 730006, Colombia
3 Investigation Group INYUMACIZO, National Open and Distance University, Bogotá 111511, Colombia
4 Natural Resources Administration Subdirectorate, Tolima Regional Autonomous Corporation—CORTOLIMA, Ibagué 73006, Colombia
* Correspondence: luisafernanda.lozano@uva.es (L.F.L.-C.); luismanuel.navas@uva.es (L.M.N.-G.)

Abstract: Due to the need to develop more agroforestry systems, the Moringa oleifera, Olea Europea, Glycine max, Brassica napus, Helianthus annuus, and Jatropha curcas are identified as unconventional species for their expansion under these systems in Colombia. With the Colombian Environmental Information System (SIAC) database, zoning was carried out according to the agroclimatic species requirements and optimal coverage for their production. As a result, a total area of 212,977.2 km^2 was identified, mainly including the departments of Casanare, Arauca, Vichada, Guajira, Córdoba, Meta, Magdalena, Cesar, Tolima, and Cundinamarca. The species and associations species with the most options for productive expansion are Moringa (75,758 km^2), Moringa, Jatropha, and Sunflower (42,515.1 km^2), Moringa and Jatropha (37,180.4 km^2), Jatropha (20,840 km^2), Jatropha and Sunflower (17,692.1 km^2), Olive (7332.1 km^2), and Soybean (3586.3 km^2). Of the potential agroforestry areas to their establishment, 36% correspond to herbaceous and/or shrubby vegetation, 34% to grasses, and 22% to heterogeneous agricultural areas. This research is the first step to representing the agronomic versatility of these promising species and their potential contribution to the diversification of the agri-food and agroforestry sectors.

Keywords: agroforestry systems; geographic information systems; oil production

check for updates

Citation: Lozano-Castellanos, L.F.; Méndez-Vanegas, J.E.; Tomatis, F.; Correa-Guimaraes, A.; Navas-Gracia, L.M. Zoning of Potential Areas for the Production of Oleaginous Species in Colombia under Agroforestry Systems. *Agriculture* **2023**, *13*, 601. https://doi.org/10.3390/agriculture13030601

Academic Editor: Simone Bergonzoli

Received: 12 January 2023
Revised: 21 February 2023
Accepted: 25 February 2023
Published: 1 March 2023

1. Introduction

The Republic of Colombia has a broad agropecuary sector due to the climatological and altitudinal variety that allows the establishment of plant and animal species for commercialization. Around 23% of the continental area corresponds to the sector: 10% agricultural, 6% livestock, 4% agroforestry, and 3% forestry production [1].

Currently, there are more than 25 agro-industrial value chains in the country. The chain of oilseeds, oils, and fats represents an integral part of the agricultural sector, since it generates a high variety of products from plant and animal materials [2]. Positioning the country as the fourth producer worldwide and the first in Latin America, palm oil is perhaps the most representative oilseed product [3], followed by soybeans, sesame, and cotton; and to a lesser extent, coconut oil, peanuts, palm kernels, corn, olive, rapeseed, and sunflower [2]. It is considered a problematic crop due to the countless investigations and technical documents that defend or point out the impacts of its production [4]. Usually cultivated under agricultural production systems based on large extensions of monocultures in Colombia, oil palm has caused some oleaginous species to cease to be competitive, while contributing to environmental and social losses associated with this form of planting [5–9]. Organizing productive areas through establishing and managing agroforestry arrangements has been considered an alternative to this problem to improve environmental sustainability without neglecting agricultural production [10].

Under the hypothesis that the establishment of other oilseed species will have a representative area in Colombia, the main objective of this research is to zone six unconventional oil crops with a track record and commercial interest as a proposal to minimize oil monocultures, strengthen the chain, and diversify agricultural production. The mentioned crops are Moringa (*Moringa oleifera)*, Olive *(Olea Europea)*, Soybean *(Glycine max)*, Rapeseed *(Brassica napus)*, Sunflower *(Helianthus annuus)*, and Jatropha *(Jatropha curcas*) The specific objectives are to identify the environmental characteristics of the country and its available land for the establishment of crops, to identify the agroclimatic requirements for each crop, and to calculate the potential agroforestry areas for the establishment of species through map zoning.

2. Materials and Methods

2.1. Spatial Data Processing

Through the free access technological platform QGIS version 3.24.2, "Tisler" (https://qgis.org/en/site/, accessed on 18 July 2022, sourced software in Colombia and Spain) with projected cartographic reference system (SRC) EPSG:4326–WGS 84, geographic information for Colombia was used for zoning the potential areas for the production of six oilseed species. Environmental characteristics published in the databases of the SIAC where selected, including the climatological factors of temperature, precipitation, biophysical conditions as altitude, drains, and coverage, and the excluded areas where agroforestry activities must not be developed (Figure 1).

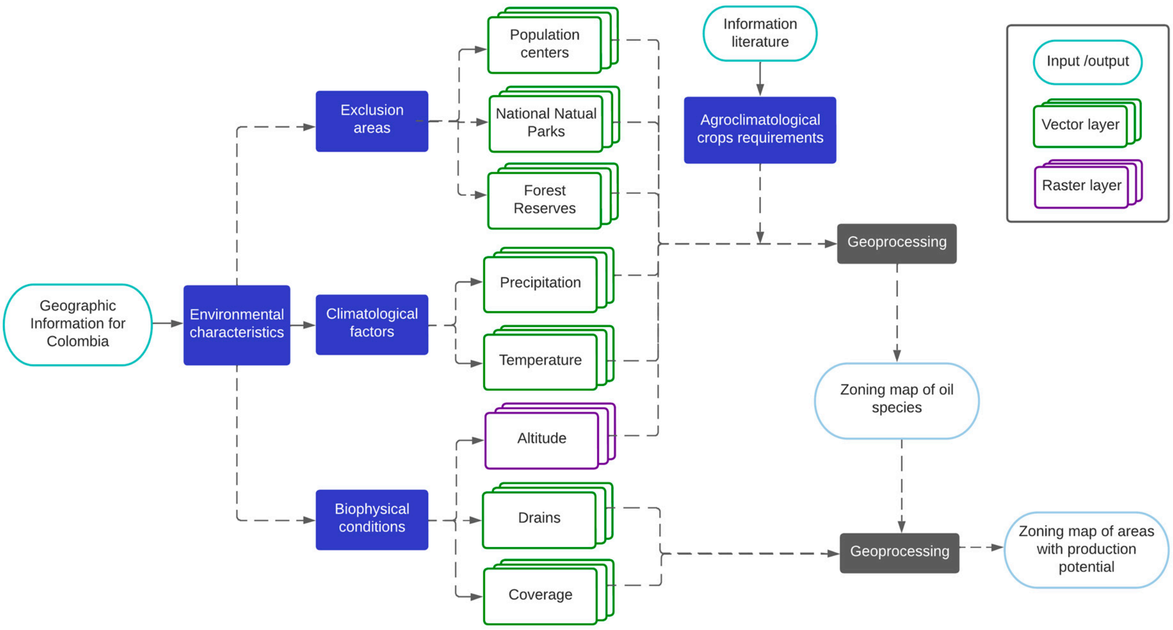

Figure 1. Geoprocessing model for potential zoning of oleaginous under agroforestry systems in Colombia.

The climatological factors were obtained through the geographic information vector layer "Total annual precipitation" of the Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM) in the year 2012, with the topics "Climate Change" and "Average annual temperature and thermal floors" [11].

The biophysical conditions were correlated with land cover and/or activities that allowed the integration of crops and the improvement of natural areas. The vector layer "Double drains" [12] was considered to validate the availability of water resources, and the "Map of ecosystems" of the Colombian Institute Agustín Codazzi (IGAC) [13] was considered to identify the agroforestry coverages, or similar, that allow the establishment of species (Table 1).

Table 1. Coverage level, category, and subcategory selected according to Corine Land Cover.

Level	Categories	Subcategories
Agricultural areas	Rotation crops	Other rotation crops Cereals Oilseeds and legumes Vegetables Tubers
	Permanent crops	Permanent crops Herbaceous permanent crops Bushy permanent crops Permanent tree crops Agroforestry crops Confined crops
	Grasses	Pastures Wooded pastures Weedy grasses
	Heterogeneous agricultural areas	Crop Mosaic Mosaic of pastures and crops Mosaic of crops, pastures, and natural spaces Mosaic pastures with natural spaces
Forests and semi-natural areas	Forests	Fragmented forest
	Areas with herbaceous and/or shrubby vegetation	Grassland Shrubland
	Open areas, without or with little vegetation	Bare and degraded land Burned areas

Altitude was the only raster layer obtained by IGAC through the Digital Elevation Model (DEM) [13]. Finally, the exclusion of population centers, National Natural Parks, and Forest Reserves (established by Law 2 of 1959) was carried out by the Colombian Spatial Data Infrastructure (ICDE) [14].

With the base cartography and the agroclimatic requirements of the crops (Section 2.2), the DEM layer was polygonized (transform from raster to vector) to execute the geoprocessing tool for vector analysis: cut (from the attribute table), with the other layers corresponding to climatological factors and exclusion areas, to extract the input information superimposed with the data required for each crop. Colombia's first map of oilseed species was obtained with this first geoprocessing. Subsequently, the information on drains and coverage was added, where a second cutting geoprocessing was carried out to obtain the zoning map of areas with agroforestry production.

2.2. Oilseed Species

The following oilseed species, cultivated but less commercialized in Colombia, and considered of national interest and importance for their contribution to the acquisition of products and socioeconomic and environmental improvement, were selected to identify their establishment in areas with agroforestry potential.

Once the agroclimatic compatibility criteria of each species were obtained (Figure 2, Table 2), the result was spatialized.

1. Moringa tree (*Moringa oleifera*) grows under tropical and subtropical climatic conditions in a wide temperature range from −3 to 49 °C, with 25–35 °C being optimal for

its growth, with annual rainfall between 300–1500 mm or even up to 2500 mm and at altitudes from 900 to 2000 masl [15–18]. The seeds of the tree have been used to obtain oils for edible, cosmetic, and industrial use [19–21]. Its leaves are used for consumption due to their high nutritional value for people and livestock. In addition, it has purifying properties for water treatment and is a species suitable for reforestation processes due to its rapid growth [22–24].

2. Olive tree (*Olea europaea*), adapts to high and low temperatures from −4 to 40 °C, the most optimal for its growth being between 20 and 30 °C; in the same way, it adapts to altitudes between 700–1700 masl and in areas with rainfall between 400–1000 mm per year [25–27]. Olive oil for human consumption is perhaps the best-known product of the tree; however, its leaves are also consumable for their medicinal properties [28,29]. As an agroforestry species, it has been used in countries such as Greece, Spain, and Morocco, where it has contributed to the productivity of the land and the improvement of area environmental conditions [30,31].
3. Soybean (*Glycine max*) climatic requirements vary between 0 and 800 masl; although, in some places, it can grow up to 3000 [32]. The temperature for the development of the crop varies between 20 and 35 °C, with 30 °C being ideal for its production [33], but other authors propose that the optimal range is between 22° and 30 °C [34]. Soybean needs at least 300 mm of water during its production cycle, which can be supplied through irrigation systems. However, an average of 3.3 mm/day, equivalent to 530 mm per cycle, is better in humid and bimodal climates, guaranteeing high rainfall in its growth stage and a decrease of these during maturation [33].
4. Rapeseed (*Brassica napus*) grows at altitudes between 50–2300 masl, requires 400–450 mm per year, and adapts to temperatures up to 10 °C during germination and up to 35 °C during seed maturation; however, to obtain a higher oil content and healthy growth, the optimum temperature ranges between 12–30 °C [34,35]. This species positively affects soil structure; can contribute to increasing cereal yields and controlling their pathogens; and has a large market for edible, industrial, and pharmaceutical use [36–38]. On the other hand, the abundance of pests in rapeseed crops is reduced by the shade of trees in agroforestry systems [39].
5. Sunflower (*Helianthus annuus*) requires between 250–1500 mm of annual precipitation, temperatures between 15–37 °C, and grows at an altitude between 0–1900 masl [34,40,41]. It is also considered one of the main oilseed species worldwide for human consumption, and for the production industry of bioenergy, medicines, and cosmetics, among others [42].
6. Jatropha (*Jatropha curcas)* is a non-traditional oilseed shrub that grows mainly in tropical areas and is used in agroforestry systems for biofuel production, reforestation, and soil improvement [43]. The crop adapts to temperatures between 15 to 35 °C, but the optimal temperature is between 18–28.5 °C. It requires rainfall between 1000–2000 mm per year and altitudes between 500–1200 masl [44,45].

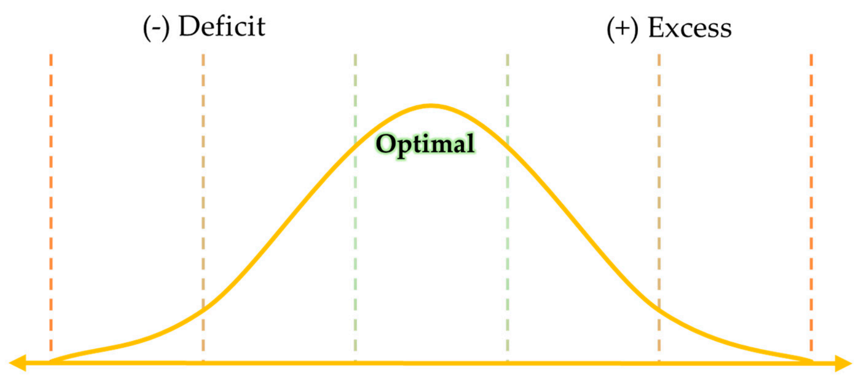

Figure 2. Graphic representation of the agroclimatic compatibility criteria.

Table 2. Agroclimatic compatibility criteria of Moringa, Olive, Soybean, Rapeseed, Sunflower, and Jatropha.

Species	Parameter	(−) Deficit		Optimal	(+) Excess	
Moringa oleifera	P (mm)	<200	200–300	300–2500	2500–2700	>2700
	T (°C)	<−3	–3–25	25–35	35–49	>49
	A (masl)	0	0–1200	1200–1800	1800–2000	>2000
Olea europaea	P (mm)	<250	250–400	400–1000	1000–1500	>1500
	T (°C)	<−7	−7–20	20–30	30–40	>40
	A (masl)	0	0–900	900–1200	1200–1700	>1700
Glycine max	P (mm)	<200	200–300	300–530	530–700	>700
	T (°C)	<4	4–22	22–30	30–40	>40
	A (masl)	0	0–800	800–1600	1600–3000	>3000
Brassica napus	P (mm)	<200	200–400	400–450	450–500	>500
	T (°C)	<5	5–12	12–30	30–35	>35
	A (masl)	<50	50–1000	1000–2000	2000–2300	>2300
Helianthus annuus	P (mm)	<250	250–600	600–1000	1000–1500	>1500
	T (°C)	<3	3–15	15–37	37–40	>40
	A (masl)	0	0–600	600–1000	1000–1900	>1900
Jatropha curcas	P (mm)	<800	800–1000	1000–2000	2000–2500	>2500
	T (°C)	<15	15–18	18–28.5	28.5–35	>35
	A (masl)	0	0–800	800–1200	1200–1400	>1400

Note: P = precipitation; T = temperature; A = altitude; < less than; > more than.

3. Results

Spatial data processing made it possible to establish the relationships between elements and climatological factors to determine the optimal areas for developing agroforestry systems (Figure 3). Exclusion zones also must be considered where agricultural activities must not be carried out by national and international law.

By this cartography, the exclusions, and the agroclimatic compatibility criteria of each species, it is finally identified that in Colombia, 18.65% (212,977.2 km^2) of its territory has areas for its potential oil production (Figure 4), mainly represented in the departments of Casanare, Arauca, Vichada, Guajira, Córdoba, Meta, Magdalena, Cesar, Tolima, and Cundinamarca (Table 3).

Figure 4 shows Moringa as the species with the greatest opportunity for expansion, representing approximately 35% (75,758 km^2) of the total identified area, followed by Jatropha with 9.8% (20,840.9 km^2), Olive with 3.4% (7332.1 km^2), and Soybean with 1.7% (3586.3 km^2).

In addition, there can be associations with more than two species that share the same agroclimatic criteria for their establishment: Moringa, Jatropha, and Sunflower represent 20% (42,515.1 km^2); Moringa and Jatropha, 17.5% (37,180.4 km^2); Jatropha and Sunflower, 8.3% (17,692.1 km^2); Moringa, Olive, and Sunflower, 2.8% (6026.8 km^2); Rapeseed and Soybean, 0.9% (1934.1 km^2); and Olive and Sunflower, 0.1% (215 km^2).

Regarding the land cover, of the total area with potential for oil production in Colombia, 36% corresponds to areas with herbaceous and/or shrubby vegetation; 34% corresponds to grasses; 22% to heterogeneous agricultural areas; and 8% is distributed between permanent and transitory crops, open areas, without or with little vegetation and fragmented forests (Figure 5).

The ten departments with the largest area of optimal agroclimatic conditions have the same national trend with the coverages (herbaceous and/or shrubby vegetation, grasses, and heterogeneous agricultural areas) and species (Moringa and its associations with Jatropha and Sunflower, and Jatropha). By contrast, the case of Soybean and its association with rapeseed, as well as the association of Moringa, Olive, and Sunflower, have more significant predominance in these departments, unlike the national trend (Table 4).

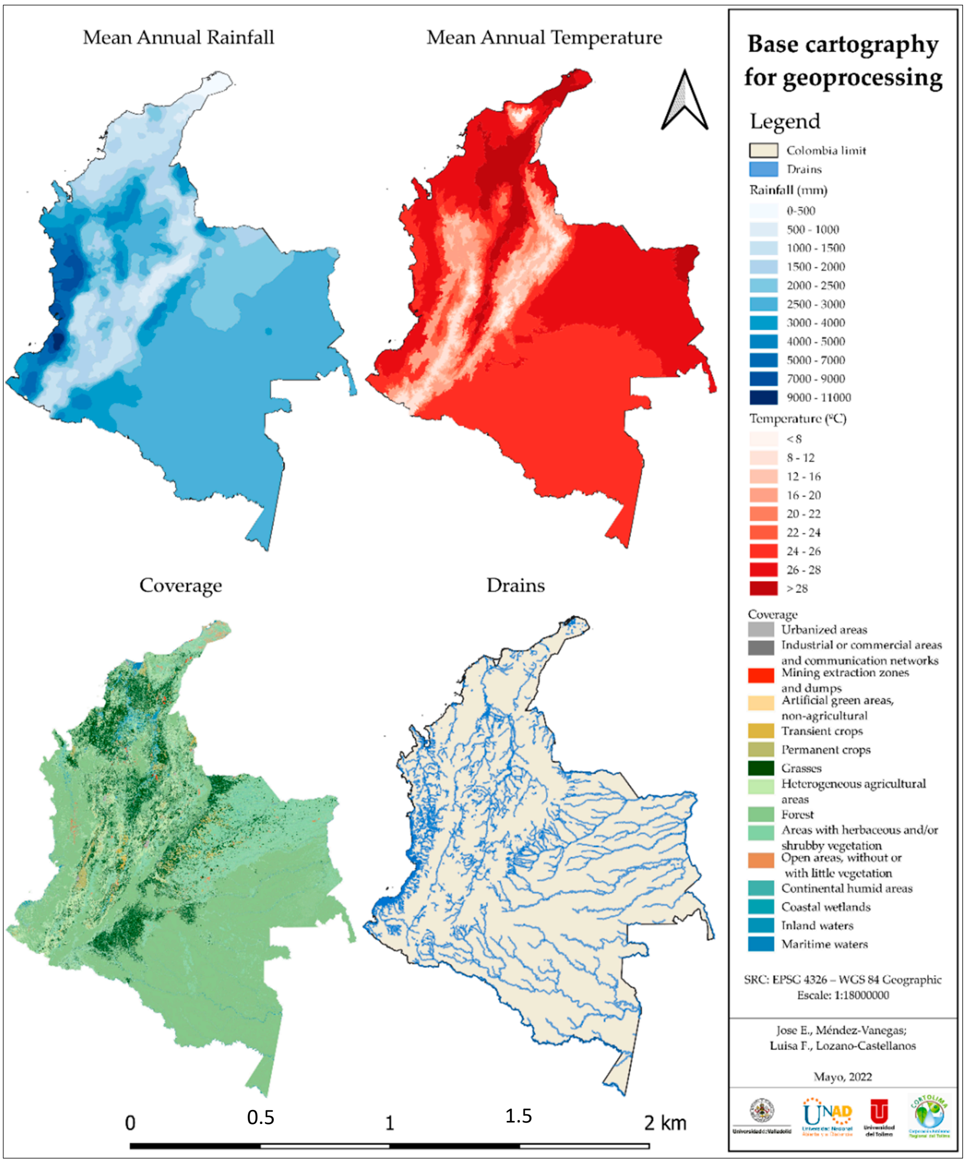

Figure 3. Base cartography for geoprocessing.

Table 3. Departmental area to produce oil species.

Departments	Area_km^2
Casanare	28,387.2
Arauca	15,122.4
Vichada	15,059.6
La Guajira	14,849.9
Cordoba	14,040
Meta	13,613
Magdalena	13,144.5
Cesar	13,069.6
Tolima	10,655.6
Cundinamarca	9743.2
Bolivar	8230.7
Huila	8156.2
Sucre	7058.1
Valle del Cauca	6410.5
Santander	6198.6

Table 3. *Cont.*

Departments	Area_km^2
Boyacá	6011.1
Norte de Santander	5994.3
Antioquia	5041.5
Cauca	4510.6
Atlántico	2793.7
Nariño	2370.8
Caquetá	1198.7
Caldas	453.8
Quindío	415.9
Choco	214.9
Risaralda	210.2
San Andres y Providencia	21.8
Putumayo	1.1
Total	212,977.2

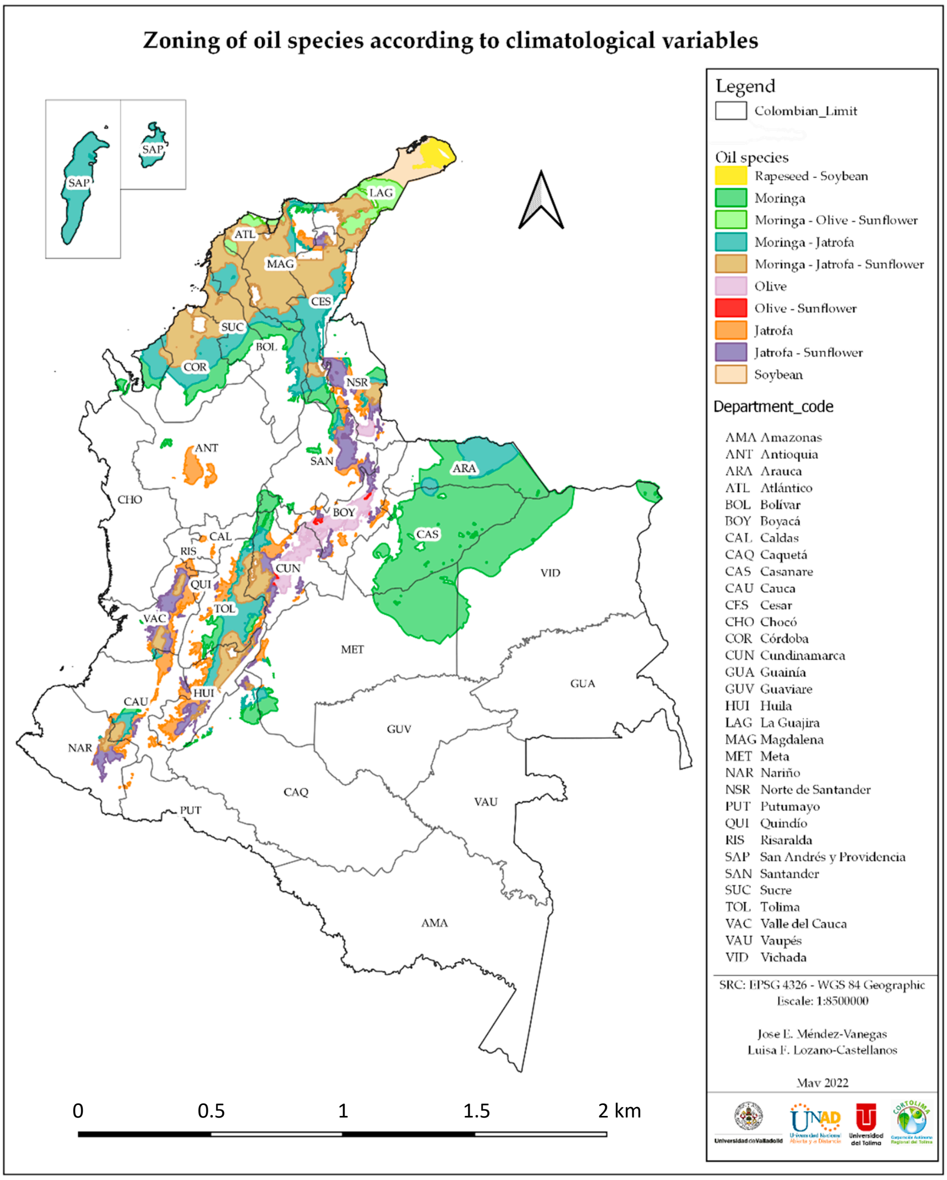

Figure 4. Zoning of oil species according to climatological variables.

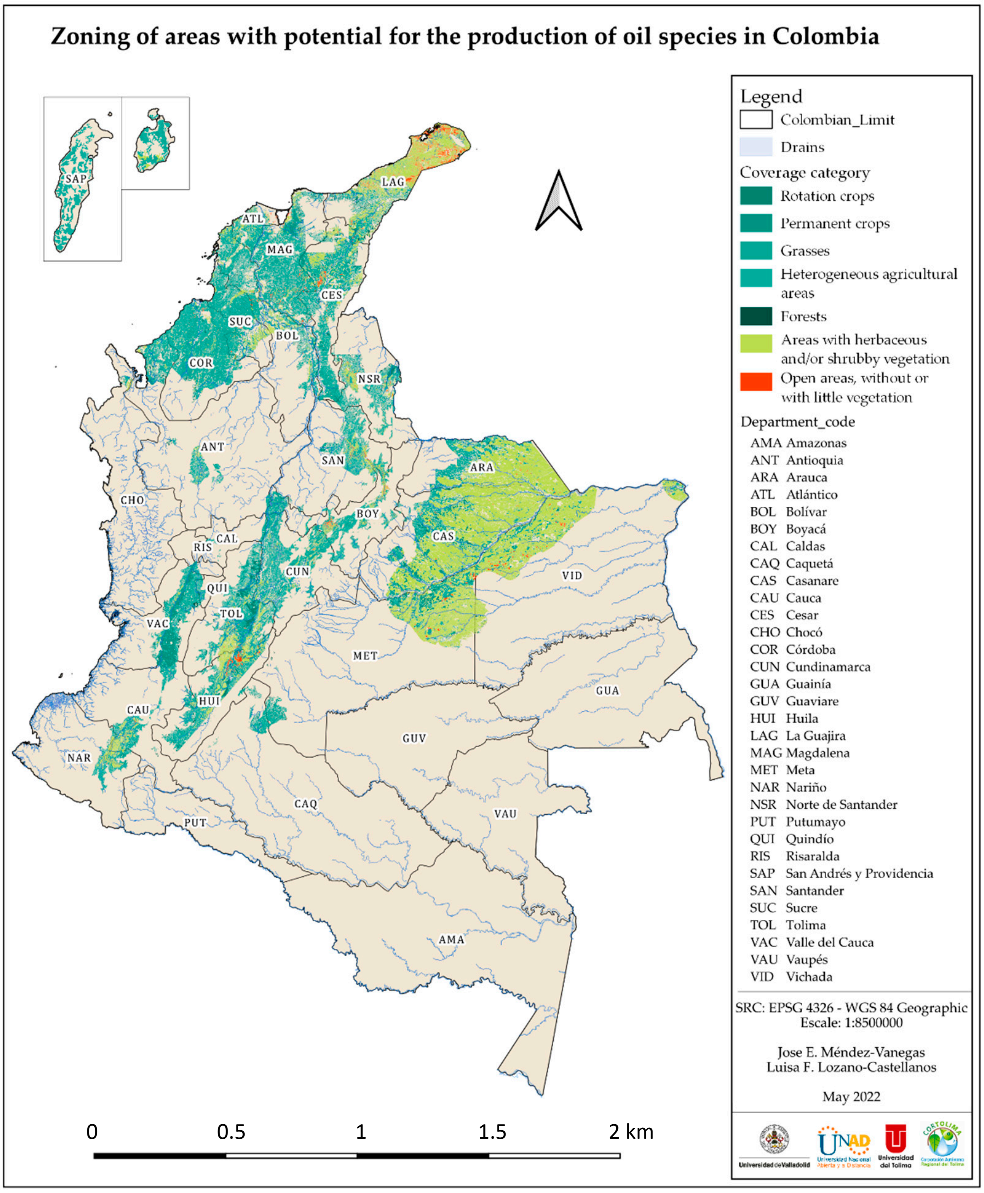

Figure 5. Zoning of areas with the potential to produce oil species in Colombia.

Table 4. Oilseed species association and its relation with the coverages: rotation crops (RC), permanent crops (PC), grasses (G), heterogeneous agricultural areas (HAA), forest (F), areas with herbaceous and/or shrubby vegetation (HSV), and open areas (OA) in the ten principal departments for production.

	(RC)	(PC)	(G)	(HAA)	(F)	(HSV)	(OA)	Total *
Casanare	1099.0	519.7	4699.7	1912.6	118.2	19,992.5	45.5	28,387.2
M	1092.9	519.7	4608.1	1891.7	114.0	19,793.8	45.5	28,065.8
M–J	6.1	-	67.7	6.2	-	194.4	-	274.3
J	-	-	23.9	14.7	4.2	4.3	-	47.1
Arauca	110.3	1.6	3090.4	646.5	91.3	11,122.7	59.6	15,122.4
M	25.9	0.4	2353.5	351.0	58.9	6849.5	46.0	9685.3
M–J	84.4	1.2	736.9	295.4	32.3	4273.2	13.6	5437.1
J	-	-	-	-	0.04	-	-	0.04

Table 4. *Cont.*

	(RC)	(PC)	(G)	(HAA)	(F)	(HSV)	(OA)	Total *
Vichada	42.4	54.4	1750.2	270.5	38.5	12,681.5	222.2	15,059.6
M	42.4	54.4	1750.2	270.5	38.5	12,681.5	222.2	15,059.6
La Guajira	50.2	59.5	2048.2	1907.6	324.7	8811.5	1648.1	14,849.9
M–O–Sun	19.5	4.2	911.4	743.1	60.6	3101.4	325.0	5165.1
S	-	-	1.2	220.3	12.0	3220.9	836.1	4290.5
M–J–Sun	30.8	54.4	1098.4	661.3	194.7	872.8	64.0	2976.4
R–S	-	-	-	207.7	23.9	1596.5	422.3	2250.4
M–J	-	0.9	37.2	74.5	32.9	19.8	0.7	166.1
M	-	-	-	0.7	0.7	-	-	1.4
Cordoba	77.0	92.1	9616.5	3637.9	70.5	498.8	47.3	14,040.1
M–J–Sun	62.7	61.3	4435.8	2095.3	2.1	187.2	40.3	6884.8
M–J	6.8	17.9	3479.5	1034.6	33.3	214.3	6.6	4793.1
M	7.5	12.8	1701.2	508.0	35.1	97.3	0.4	2362.2
Meta	431.6	390.9	2589.4	1129.2	115.5	8789.9	166.6	13,613.0
M	431.6	390.9	2474.2	1070.5	75.1	8789.9	166.0	13,398.0
M–J	-	-	113.5	57.9	21.8	-	-	193.2
J	-	-	1.7	0.8	18.6	-	0.6	21.8
Magdalena	27.2	709.4	8255.0	2921.4	160.2	847.7	223.5	13,144.5
M–J–Sun	23.2	615.7	6852.2	1571.7	27.3	576.2	161.4	9827.7
M–J	3.8	32.0	1131.6	817.3	55.8	163.8	27.4	2231.7
M	-	11.9	217.5	262.2	46.1	26.5	23.7	587.8
J	-	1.2	16.3	207.1	21.8	27.6	-	274.0
M–O–Sun	0.2	48.5	36.7	49.8	3.7	28.9	10.7	178.5
J–Sun	-	0.1	0.6	13.4	5.6	24.7	0.2	44.7
Cesar	128.7	935.2	7292.9	2424.8	141.8	1929.4	216.9	13,069.6
M–J–Sun	56.4	286.5	3374.3	738.4	29.9	1237.7	155.1	5878.3
M–J	72.3	424.1	3238.0	1343.7	46.5	370.3	52.6	5547.6
M	-	187.7	594.4	91.4	0.5	-	6.4	880.4
J	-	37.0	73.6	176.1	30.9	148.8	-	466.4
J–Sun	-	-	12.6	75.1	33.8	172.6	2.7	296.9
Tolima	1270.1	196.6	3574.4	3626.7	55.3	1853.8	78.8	10,655.6
M–J	641.6	53.1	1747.1	1271.7	-	732.3	31.9	4477.7
M–J–Sun	602.6	8.9	596.0	507.7	-	526.9	34.3	2276.5
J	13.0	129.2	540.4	1318.8	54.7	109.4	2.6	2168.1
M	12.9	3.8	663.2	474.7	0.6	477.4	9.9	1642.6
J–Sun	-	1.6	27.6	53.8	-	7.7	-	90.7
Cundinamarca	125.3	106.1	3984.5	4591.3	50.6	866.4	19.1	9743.2
O	71.5	62.5	1418.2	1441.1	7.5	559.9	16.4	3577.0
M–J–Sun	53.7	29.2	757.6	916.5	2.3	167.7	1.5	1928.4
J–Sun	-	9.3	340.9	1084.1	13.6	20	0.3	1468.1
J	-	3.1	404.9	692.1	7.7	53.4	0.6	1161.8
M	-	1.5	610.1	194.5	16.5	4.2	0.2	827.0
M–J	-	-	435.6	187.9	2.9	61.3	0.2	687.8
O–Sun	-	0.6	17.3	74.6	0.1	-	-	92.6
M–O–Sun	-	-	-	0.6	-	-	-	0.6

Note: * total in km^2; for those without area, the symbol "–" is applied; M = Moringa; J = Jatropha; S = Sunflower; O = Olive; M–J = Moringa and Jatropha; R–S = Rapeseed and Soybean; M–O–Sun = Moringa, Olive, and Sunflower; M–J–Sun = Moringa, Jatropha, and Sunflower; J–Sun = Jatropha and Sunflower; O–Sun = Olive and Sunflower; rotation crops = RC; permanent crops = PC; grasses = G; heterogeneous agricultural areas = HAA; forest = F; areas with herbaceous and/or shrubby vegetation = HSV; open areas, without or with little vegetation = OA.

4. Discussion

Colombia has government institutions in charge of generating and processing spatial data for the characterization of the islands and continental areas of the country from different thematic areas, the agroforestry systems being less developed thematically. These institutions have progressed with free access to cartographic views and downloadable files in vector or raster format, establishing the zoning of agricultural activities with their aptitude and attitude for some species.

The country's geographic information systems thoroughly characterize the African palm. In fact, the 261,965 hectares dedicated to the production of oilseeds in 2004, where oil palm had a distribution of 60% [3], and the subsequent increase of 646,943 hectares in 2021, with the participation of oil palm of 90% [46], have caused efforts to focus on the expansion of this crop, leaving aside the investigation or specialization of other species, such as those studied in this investigation. Therefore, it is a setback in the national investigation of other alternatives for the production of oilseed species.

Regarding its production under monoculture conditions, oil palm produces between 6 and 10 times more per hectare than the other oilseeds known to date, which makes it economically profitable, but not environmentally sustainable due to high deforestation rates and changes in soil dynamics attributed to its expansion [47,48]. However, this situation can be reduced by substituting or associating other oilseed species that will allow more significant ecosystem interaction and guarantee production within the framework of sustainable development, e.g., the association of Moringa and Jatropha [49].

In the case of Soybean cultivation, which is the second crucial oilseed, there are only production, trade, and market indicators from institutions such as the National Administrative Department of Statistics (DANE); ProColombia, a government agency of the Government of Colombia; and the Ministry of Agriculture and Rural Development. The indicators identify the crop presence in the departments or municipalities without geospatial information or in agroforestry systems.

Several studies have pointed out the importance of applying geographic information tools in agriculture to monitor species, update the occupied area, and identify harvest opportunities, among others [50–57]. In Colombia's case, disabling these techniques to different species limits producers, citizens, and investigators from comparing, identifying alternative crops, and studying national or international market opportunities.

For instance, the advantage of newly suitable areas for the establishment of the Soybean crop and Jatropha identified in this research, compared with other studies with a high representation in other departments [58,59], will allow a broader representation for decision-making based on geo-referenced parameters and technologies in agriculture. On the other hand, despite recent agronomic and economic studies on the establishment of Moringa in Colombia, it has not yet taken on sufficient importance for greater use; in spatialization issues, two investigations are registered that have used spatial data to approach the possible settlement areas according to some environmental variables [21,60]. Specifically, the olive tree has not been established as a predominant crop in the country, so there is not too much information on this species. Crops are recorded in the department of Boyacá, an area that, according to the zoning carried out, agrees with the agronomic characteristics of the species [61].

Finally, the Rural Agricultural Planning Unit (UPRA), through its Information System for Rural Agricultural Planning, has developed a suitability map for oil palm in Colombia [62], which, compared with our results, allows for establishing a direct relationship between the variables studied and the parameters considered by UPRA for the definition of zones of physical, ecological, and socioeconomic aptitude. Both zonings identify similar regions for establishing the oil palm and the six species studied, offering the opportunity to substitute or associate the oilseed species in the country.

For future lines of research, it is recommended to consider other variables for a more complete economic and environmental feasibility analysis, e.g., physicochemical factors of the soil, edaphological requirements of crops, production data, direct sampling in the field (quantification of biodiversity), hydro climatological information, and the use of other tools and geoprocessing techniques in GIS for modeling and forecasting [53,63–67]. The use of these techniques is directly related to the scope of the investigation.

5. Conclusions

The use of technological platforms for the processing of geographic information of the areas with an aptitude to produce oilseeds allows for providing results for the planning and decision-making in the rural agroforestry sector of the Colombian territory of each of the productive chains studied.

Although it is true that in Colombia, the production of oily material is obtained from palm oil, soybeans, sesame, and cotton, it can be concluded that the species studied with the best potential for their production under agroforestry systems are Sunflower, Moringa, and Jatropha. The first one has a potential area in the north and center of the country, with the most significant impact in the departments of La Guajira, Atlántico, Sucre, Magdalena, Córdoba, Huila, Valle del Cauca, Santander, North of Santander, and Cundinamarca. At the same time, Moringa and Jatropha can be established in the north, center, and west of the country, mainly in the departments of Tolima, Huila, Valle, Valle del Cauca, Casanare, and Arauca. However, there are other regions with less area potential, but with the same agroforestry importance, such as Nariño and Cauca to the southwest and Meta and Vichada to the east.

Moringa, as a species established individually or in association with the Olive Tree, the Sunflower, and the Jatropha, is the species with the most significant potential in the country, with excellent representation in most of the coverages. The opposite is the case with Canola, which is the species with the least predominance for its establishment, located only in the department of La Guajira, where areas with herbaceous and/or shrubby vegetation and open areas with little or no vegetation predominate, which can be an excellent opportunity for the recovery of soils and restoration of ecosystems.

Regarding coverage, heterogeneous agricultural areas and grasses are the main ones for establishing the species. Although these covers are occupied by agricultural activities linked to transient monocultures and extensive livestock, respectively, they require a transition to agroforestry systems to promote sociocultural changes for the incorporation and integration of new species (such as oilseeds), the diversification of agroforestry, and the minimization of silvopastoral systems.

Considering that the largest production of oil is of vegetable origin, the resulting areas with potential to produce oilseeds can contribute to the increase in planted hectares in relation to the existing one, specifically for oil palm plantations, and thereby improve the participation in Latin American production.

The zoning of oilseed species for production under agroforestry systems was based on precipitation, temperature, altitude, and coverages parameters, a first step for determining potential areas in the country. However, it is necessary to consider other agro-environmental aspects when defining oilseed species, such as environmental restrictions; environmental permits; and other parameters of conflict of supply, vocation, and land use.

Author Contributions: Conceptualization, L.F.L.-C., J.E.M.-V. and L.M.N.-G.; methodology, L.F.L.-C., J.E.M.-V. and A.C.-G.; software, L.F.L.-C. and J.E.M.-V.; formal analysis, L.F.L.-C., J.E.M.-V., A.C.-G. and L.M.N.-G.; investigation, L.F.L.-C., J.E.M.-V. and F.T.; resources, J.E.M.-V. and L.M.N.-G.; data curation, L.F.L.-C., J.E.M.-V. and F.T.; writing—original draft preparation, L.F.L.-C., J.E.M.-V. and F.T.; writing—review and editing, L.F.L.-C., J.E.M.-V., A.C.-G. and L.M.N.-G.; visualization, L.F.L.-C., J.E.M.-V. and F.T.; supervision, F.T.; A.C.-G. and L.M.N.-G.; project administration, L.F.L.-C., J.E.M.-V., A.C.-G. and L.M.N.-G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: The main author of this article thanks her work team, tutors, and directors who motivate the writing of this article. Luisa F. Lozano-Castellanos has been financed under the call predoctoral recruitment of research staff, co-financed by the Ministry of Education (Junta de Castilla y León (Spain) and the European Social Fund.

Conflicts of Interest: The authors declare no conflict of interest, and the funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Departamento Administrativo Nacional de Estadística–DANE. Encuesta Nacional Agropecuario (ENA) 2017. Boletín Técnico. Available online: https://www.agronet.gov.co/Lists/Boletin/Attachments/2575/boletin_ena_2017.pdf (accessed on 23 September 2022). (In Spanish)
2. Espinal, C.; Martínez, E.; González, E. *La Cadena de Oleaginosas, GRASAS y aceites en Colombia, una Mirada Global de su Estructura y Dinámica 1991–2005*; Ministerio de Agricultura y Desarrollo Rural y Observatorio Agrocadenas de Colombia: Bogotá, Colombia, 2005. (In Spanish)
3. Ministerio de Agricultura y Desarrollo Rural. *Cadena de Palma de Aceite, Indicadores e Instrumentos*; Ministerio de Agricultura y Desarrollo Rural: Bogotá, Colombia, 2020. (In Spanish)
4. Murphy, D.J.; Gogging, K.; Paterson, R.R.M. Oil palm in the 2020s and beyond: Challenges and solutions. *CABI Agric. Biosci.* **2021**, *2*, 39. [CrossRef]
5. Gonzalo, A. estado del conocimiento de la biodiversidad en Colombia y sus amenazas. Consideraciones para fortalecer la interacción ciencia-política. *Rev. Acad. Colomb. Cienc. Exact. Fís. Nat.* **2011**, *35*, 491–507. (In Spanish)
6. Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM); Instituto de Investigaciones Marinas y Costeras José Benito Vives de Andréis–INVEMAR; Instituto de Investigaciones Ambientales del Pacífico–IIAP; Instituto de Investigación de Recursos Biológicos Alexander von Humboldt–IAvH. *Informe del Estado del Ambiente y de los Recursos Naturales Renovables 2016*; Casallas-Martínez, I.M., Cortés-Guardiola, L.D.P., Moreno-Saboya, Y.A., Eds.; Institute of Hydrology, Meteorology and Environmental Studies: Bogotá, Colombia, 2017. (In Spanish)
7. Meijaard, E.; Brooks, T.M.; Carlson, K.M.; Slade, E.M.; Garcia-Ulloa, J.; Gaveau, D.L.A.; Lee, J.S.H.; Santika, T.; Juffe-Bignoli, D.; Struebig, M.J.; et al. The environmental impacts of palm oil in context. *Nat. Plants* **2020**, *6*, 1418–1426. [CrossRef] [PubMed]
8. Vargas, L.E.P.; Laurance, W.F.; Clements, G.R.; Edwards, W. The Impacts of Oil Palm Agriculture on Colombia's Biodiversity: What We Know and Still Need to Know. *Trop. Conserv. Sci.* **2015**, *8*, 828–845. [CrossRef]
9. Vijay, V.; Pimm, S.L.; Jenkins, C.N.; Smith, S.J. The Impacts of Oil Palm on Recent Deforestation and Biodiversity Loss. *PLoS ONE* **2016**, *11*, e0159668. [CrossRef] [PubMed]
10. Departamento Administrativo Nacional de Estadística–DANE. *Boletín Mensual, Insumos y Factores Asociados a la Producción Agropecuaria*; DANE, Ministerio de Agricultura y Desarrollo Rural de Colombia, Sistema de Información de Precios y Abastecimiento del Sector Agropecuario (SIPSA): Bogotá, Colombia, 2012; Volume 6, pp. 1–76. (In Spanish)
11. Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM). Información Geográfica de Datos Abiertos del IDEAM. Available online: http://www.ideam.gov.co/inicio?p_p_id=101&p_p_lifecycle=0&p_p_state=maximized&p_p_mode=view&_101_struts_action=%2Fasset_publisher%2Fview_content&_101_assetEntryId=91482640&_101_type=content&_101_urlTitle=capas-geo (accessed on 2 February 2022). (In Spanish)
12. Corporación Autónoma Regional del Tolima–CORTOLIMA. Datos abiertos CORTOLIMA. Available online: https://cortolima.gov.co/cortolima/datos-abiertos (accessed on 3 February 2022). (In Spanish)
13. Instituto Geográfico Agustín Codazzi–IGAC. Datos Abiertos IGAC. Available online: https://geoportal.igac.gov.co/contenido/datos-abiertos-igac (accessed on 15 February 2022). (In Spanish)
14. Infraestructura Colombiana de Datos Espaciales–ICDE. Available online: https://www.icde.gov.co/ (accessed on 2 February 2022). (In Spanish)
15. Huda, N.; Khan, S.; Haque, M.; Roy, B.; Sarker, N. Seasonal weather impacts on biomass production of *Moringa oleifera* at different fertilizer doses. *Int. J. Health Anim. Sci. Food Saf.* **2017**, *4*, 12–23. [CrossRef]
16. Godino, M.; Arias, C.; Izquierdo, M. *Moringa oleifera*: Potential areas of cultivation on the Iberian Peninsula. *Acta Hortic.* **2017**, 405–412. [CrossRef]
17. Rajbhar, Y.P.; Rajbhar, G.; Pl, R.; Shukla, S.; Kumar, M. Grow Moringa (*Moringa oleifera*), the miracle tree on the earth. *Hortic. Int. J.* **2018**, *2*, 166–172. [CrossRef]
18. Shimelis, S. Suitability Analysis for *Moringa Oleifera* Tree Production in Ethiopia—A Spatial Modelling Approach. *International J. Curr. Res. Acad. Rev.* **2020**, *8*, 6–15. [CrossRef]
19. González, F.J. Un estudio transversal de *Moringa oleifera* Lam. (Moringaceae). *Rev. Dominguezia* **2018**, *34*, 5–25.
20. Karthickeyan, V. Effect of cetane enhancer on *Moringa oleifera* biodiesel in a thermal coated direct injection diesel engine. *Fuel* **2019**, *235*, 538–550. [CrossRef]
21. Castro, A. El árbol Moringa (*Moringa oleífera* Lam.): Una Alternativa Renovable para el Desarrollo de los Sectores Económicos y Ambientales de Colombia. Tesis de Especialización. Universidad Militar Nueva Granada: Bogotá, Colombia, 2013. (In Spanish)
22. Sanchez, M.; Dalia, I.; Núñez, J.A.; Reyes, C.; Ramirez, B.; Lopez, J. Nutritional quality of edible parts of *Moringa oleifera*. *Food Anal. Methods* **2010**, *3*, 175–180. [CrossRef]
23. Sandoval, M.; Laines, J. *Moringa oleifera* una alternativa para sustituir coagulantes metálicos en el tratamiento de aguas superficiales. *Ingeniería* **2013**, *17*, 93–101. (In Spanish)

24. Bojorge, S.H.; Cawich, Z.N.; Lejarza, M.G.; Moncada, C.G. Eficacia de la semilla de *Moringa oleífera* en el aclaramiento del agua. *Univ. Y Cienc.* **2017**, *9*, 31–44. [CrossRef]
25. Arenas-Castro, S.; Gonçalves, J.F.; Moreno, M.; Villar, R. Projected climate changes are expected to decrease the suitability and production of olive varieties in southern Spain. *Sci. Total Environ.* **2020**, *709*, 136161. [CrossRef]
26. Ozturk, M.; Altay, V.; Gönenç, T.; Unal, B.; Efe, R.; Akçiçek, E.; Bukhari, A. An Overview of Olive Cultivation in Turkey: Botanical Features, Eco-Physiology and Phytochemical Aspects. *Agronomy* **2021**, *11*, 295. [CrossRef]
27. Petruccelli, R.; Bartolini, G.; Ganino, T.; Zelasco, S.; Lombardo, L.; Perri, E.; Durante, M.; Bernardi, R. Cold Stress, Freezing Adaptation, Varietal Susceptibility of *Olea europaea* L.: A Review. *Plants* **2022**, *11*, 1367. [CrossRef] [PubMed]
28. Basuny, A.M. Olive Leaves Healthy Alternative for Green Tea. *Curr. Trends Biomed. Eng. Biosci.* **2018**, *14*, 555889. [CrossRef]
29. Nicolì, F.; Negro, C.; Vergine, M.; Aprile, A.; Nutricati, E.; Sabella, E.; Miceli, A.; Luvisi, A.; De Bellis, L. Evaluation of Phytochemical and Antioxidant Properties of 15 Italian *Olea europaea* L. Cultivar Leaves. *Molecules* **2019**, *24*, 1998. [CrossRef] [PubMed]
30. Brunori, E.; Maesano, M.; Moresi, F.V.; Matteucci, G.; Biasi, R.; Mugnozza, G.S. The hidden land conservation benefits of olive-based (*Olea europaea* L.) landscapes: An agroforestry investigation in the southern Mediterranean (Calabria region, Italy). *Land Degrad. Dev.* **2019**, *31*, 801–815. [CrossRef]
31. Temani, F.; Bouaziz, A.; Daoui, K.; Wery, J.; Barkaoui, K. Olive agroforestry can improve land productivity even under low water availability in the South Mediterranean. *Agric. Ecosyst. Environ.* **2020**, *307*, 107234. [CrossRef]
32. Aceves, N.; Juárez, J.F.; Palma, D.J.; López, R.; Rivera, B.; Rincón, J.A.; Morales, R.; Hernández, R.; Martínez, A. *Estudio para Determinar Zonas de Alta Potencialidad del Cultivo de la Soya (Glycine max (L) Merril) en el Estado de Tabasco*; Gobierno del Estado de Tabasco y Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación: Madrid, México, 2008. (In Spanish)
33. Hernández, A.J.; Tobía, C.M.; Zocco, J.L. *Nuevo enfoque en la producción de la soya (Glycine max. L. Merr.). En Venezuela. Producción de Semillas en Venezuela*; Lauretin, H.E., Ed.; Ediciones Astro Data, S.A.: Maracaibo, Venezuela, 2020; pp. 274–306. (In Spanish)
34. Ruiz, J.A.; Medina, G.; González, I.J.; Flores, H.E.; Ramírez, G.; Ortiz, C. *Requerimientos Agroecológicos de Cultivos*, 2nd ed.; INIFAP, Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias-CIRPAC-Campo Experimental Centro Altos de Jalisco: Jalisco, México, 2013; Volume 3, 564p. (In Spanish)
35. Bazzaz, M.; Hossain, A.; Farooq, M.; Alharby, H.; Bamagoos, A.; Nuruzzaman; Khanum, M.; Hossain, M.; Kizilgeci, F.; Öztürk, F.; et al. Phenology, growth and yield are strongly influenced by heat stress in late sown mustard (*Brassica* spp.) varieties. *Pak. J. Bot.* **2020**, *52*, 1189–1195. [CrossRef] [PubMed]
36. Marjanović-Jeromela, A.; Terzić, S.; Jankulovska, M.; Zorić, M.; Kondić-Špika, A.; Jocković, M.; Hristov, N.; Crnobarac, J.; Nagl, N. Dissection of Year Related Climatic Variables and Their Effect on Winter Rapeseed (*Brassica napus* L.) Development and Yield. *Agronomy* **2019**, *9*, 517. [CrossRef]
37. Ganya, S.; Svotwa, E.; Katsaruware, R.D. Performance of Two Rape (*Brassica napus*) Cultivars under Different Fertilizer Management Levels in the Smallholder Sector of Zimbabwe. *Int. J. Agron.* **2018**, *2018*, 2351204. [CrossRef]
38. Robson, M.; Fowler, S.; Lampkin, N.; Leifert, C.; Leitch, M.; Robinson, D.; Watson, C.; Litterick, A. The Agronomic and Economic Potential of Break Crops for Ley/Arable Rotations in Temperate Organic Agriculture. *Adv. Agron.* **2002**, *77*, 369–427. [CrossRef]
39. Guenat, S.; Kaartinen, R.; Jonsson, M. Shade trees decrease pest abundances on brassica crops in Kenya. *Agrofor. Syst.* **2017**, *93*, 641–652. [CrossRef]
40. Debaeke, P.; Casadebaig, P.; Flenet, F.; Langlade, N. Sunflower crop and climate change: Vulnerability, adaptation, and mitigation potential from case-studies in Europe. *OCL* **2017**, *24*, D102. [CrossRef]
41. Černý, I.; Veverková, A.; Kovár, M.; Pačuta, V.; Molnárová, J. Influence of temperature and moisture conditions of locality on the yield formation of sunflower (*Helianthus annuus* L.). *Acta Univ. Agric. Et Silvic. Mendel. Brun.* **2014**, *59*, 99–104. (In Spanish) [CrossRef]
42. Turchetto, R.; Trombetta, L.; Rosa, G.; Volpi, G.; Barros, S. Production components of sunflower cultivars at different sowing times. *Pesqui. Agropecuária Tropical.* **2021**, *51*, 1–6. [CrossRef]
43. González, R.; Juárez, J.F.; Aceves, L.A.; Rivera, B.; Guerrero, A. Zonificación edafoclimática para el cultivo de *Jatropha curcas* L., en Tabasco, México. *Investig. Geográficas Boletín Del Inst. De Geogr. UNAM* **2015**, *86*, 25–37. (In Spanish) [CrossRef]
44. Ewunie, G.A.; Lekang, O.I.; Morken, J.; Yigezu, Z.D. Characterizing the potential and suitability of Ethiopian variety Jatropha curcas for biodiesel production: Variation in yield and physicochemical properties of oil across different growing areas. *Energy Rep.* **2021**, *7*, 439–452. [CrossRef]
45. Subedi, C.K.; Chaudhary, R.P.; Kunwar, R.M.; Bussmann, R.W.; Paniagua, N.Y. *Jatropha curcas* L. Euphorbiaceae. In *Ethnobotany of the Himalayas. Ethnobotany of Mountain Regions*; Kunwar, R.M., Sher, H., Bussmann, R.W., Eds.; Springer: Cham, Switzerland, 2021. [CrossRef]
46. Pérez-Marulanda, N. Balance 2021 y Perspectivas 2022 de la Agroindustria de la PALMA de Aceite. Available online: https://web.fedepalma.org/sites/default/files/04032022_Balance2021_y_perspectivas_2022delaagroindustria_de_la_palma_de_aceite_CMG.pdf (accessed on 15 December 2022).
47. Furumo, P.R. Oportunidades para la palma de aceite sostenible en Colombia. *Palmas* **2019**, *40*, 188–196.
48. Ocampo-Peñuela, N.; Garcia-Ulloa, J.; Ghazoul, J.; Etter, A. Quantifying impacts of oil palm expansion on Colombia's threatened biodiversity. *Biol. Conserv.* **2018**, *224*, 117–121. [CrossRef]

49. Noulèkoun, F.; Khamzina, A.; Naab, J.B.; Khasanah, N.; van Noordwijk, M.; Lamers, J.P.A. Climate Change Sensitivity of Multi-Species Afforestation in Semi-Arid Benin. *Sustainability* **2018**, *10*, 1931. [CrossRef]
50. Ochoa, D.; Forero, A.; Cangrejo, L. *Actualidad y Tendencias de la Agricultura de Precision–Present and Trends of Precision Agriculture in the Twenty-First Century*; Bogotá, Colombia, 2012; pp. 1–14. Available online: https://www.researchgate.net/publication/324156309_Actualidad_y_tendencias_de_la_Agricultura_de_Precision (accessed on 1 November 2022).
51. López, M. Tecnologías de Información Geográfica: Una alternativa en el Sector Agrícola de Sinaloa. Conferencia: Diplomado de Actualización y Titulación en Fitosanidad de Hortalizas; México, 2014; p. 1. Available online: https://docplayer.es/52540974-Tecnologias-de-informacion-geografica-una-alternativa-en-el-sector-agricola-de-sinaloa.html (accessed on 1 November 2022). (In Spanish)
52. Rodriguez, L. Agricultura de precisión en el mundo y en Colombia: Revisión bibliográfica. Tesis de licenciatura en Ingeniería agrícola. Universidad del Valle: Santiago de Cali, Colombia, 2020. (In Spanish)
53. Parra, C.R.; Ramirez, A.D.; Navas-Gracia, L.M.; Gonzales, D.; Correa-Guimaraes, A. Prospects for Bioenergy Development Potential from Dedicated Energy Crops in Ecuador: An Agroecological Zoning Study. *Agriculture* **2023**, *13*, 186. [CrossRef]
54. Cortez-Núñez, J.A.; Gutiérrez-Castillo, M.E.; Mena-Cervantes, V.Y.; Terán-Cuevas, Á.R.; Tovar-Gálvez, L.R.; Velasco, J. A GIS Approach Land Suitability and Availability Analysis of Jatropha Curcas L. Growth in Mexico as a Potential Source for Biodiesel Production. *Energies* **2020**, *13*, 5888. [CrossRef]
55. Yun, S.D.; Gramig, B.M. Agro-Climatic Data by County: A Spatially and Temporally Consistent U.S. Dataset for Agricultural Yields, Weather and Soils. *Data* **2019**, *4*, 66. [CrossRef]
56. Carrión, J.M.; Rodríguez, O.A.V.; López, F.G.; Wassenaar, O.M.P. Potencial agroecológico de Moringa oleifera Lam. para el estado de Veracruz. *Rev. Mex. De Cienc. For.* **2022**, *13*, 42–63. [CrossRef]
57. Meira, S.; Rodriguez-Baide, J.; Confalone, A.; Fatecha-Fois, D.; Fernandes, J.; Perez-Gonzalez, O.; Van Den Berg, M. *Modelación del Cultivo de Soja en Latinoamérica, EUR 29057 ES*; Publications Office of the European Union: Luxembourg, 2019; ISBN 978-92-79-77709-7. [CrossRef]
58. Ministerio de Agricultura y Desarrollo Rural. In *Cadena de soya, Dirección de cadenas agrícolas y forestales*; 2019. Available online: https://sioc.minagricultura.gov.co/AlimentosBalanceados/Documentos/2019-03-30%20Cifras%20Sectoriales%20Soya.pdf (accessed on 29 November 2022). (In Spanish)
59. Goana, J. *Identificación de Áreas Aptas para el Cultivo del Piñón (Jatropha curcas L.) en Colombia, como Alternativa de Obtención de Biocombustible*; Ecólogo, Pontificia Universidad Javeriana: Bogotá, Colombia, 2009. (In Spanish)
60. Lozano, L. Composición del Aceite de las Semillas de *Moringa oleifera* y Evaluación de Sostenibilidad para su Implementación como Cultivo Agroforestal en Colombia. Máster Thesis, Universidad de Valladolid, Palencia, Spain, 2019. (In Spanish).
61. Garcia, J.; Cheverria, E. Comportamiento fenológico del olivo (*Olea europaea* L.) en el Alto Ricaurte (Boyacá). *Rev. Logos Cienc. Y Tecnol.* **2014**, *6*, 1–13. (In Spanish) [CrossRef]
62. Unidad de Planificación Rural Agropecuaria. Sistema de Información para la Planificación Rural Agropecuaria, SIPRA. Available online: https://sipra.upra.gov.co/nacional (accessed on 14 February 2023).
63. Morgounov, A.; Abubakr, M.; Alhendi, A.; Alkhatran, A.; Alhuwaymil, H.; Ghosh, K. Agroclimatic Zones and Cropping Systems in the Southwestern Regions of the Kingdom of Saudi Arabia: Characterization, Classification and Improvement Potential. *Crops* **2022**, *2*, 186–201. [CrossRef]
64. Caldana, N.F.d.S.; Nitsche, P.R.; Martelócio, A.C.; Rudke, A.P.; Zaro, G.C.; Batista Ferreira, L.G.; Zaccheo, P.V.C.; Colucci de Carvalho, S.L.; Martins, J.A. Agroclimatic Risk Zoning of Avocado (*Persea americana*) in the Hydrographic Basin of Paraná River III, Brazil. *Agriculture* **2019**, *9*, 263. [CrossRef]
65. Ngolo, A.; Fernandes-Filho, E.; Ferreira, W.; Fernandes, R. Agroclimatic zoning for coffee crop in Angola. *Pesqui. Agropecu. Trop.* **2018**, *48*, 19–28. [CrossRef]
66. Ramírez-Jaramillo, G.; Lozano-Contreras, M.G.; Ramírez-Silva, J.H. Agroclimatic Conditions for Growing *Sorghum bicolor* L. Moench, under Irrigation Conditions in Mexico. *Open Access Libr. J.* **2020**, *7*, 1–14. [CrossRef]
67. Lozano-Mendoza, P.; Gonzales-Osorio, B.B.; Puente-Monar, N.; Ochoa, L.F.S. Geographic distribution of coca cultivation: Multicriteria analysis based on agroclimatic and biophysical parameters. *NeuroQuantology* **2022**, *20*, 6646–6657. [CrossRef]