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Use of GIS in Selecting Suitable Tree Crop Cultivation Sites in Mountainous Less Favoured Areas: An Example from Greece

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Abstract: The aim of this paper is the selection of suitable tree crop cultivation sites in mountainous less favoured areas, as a forest policy measure under the scope of sustainable development. Ten different crop types were proposed as being most suitable in the study area, Pierion Municipal Unit, which is located in the Municipality of Katerini, in the Pieria Prefecture of Greece. In order to determine the most suitable sites for cultivation, data layers that involved the factors of topography, climate, pedology and geology were derived from existing maps and free-of-charge datasets, so that they could be consequently processed with the aid of Geographic Information Systems (GIS). The data processing was performed by following criteria, which were established in accordance with the current literature and were translated into Boolean algebra expressions. The latter helped to identify locations where the values of the factors that were employed were most favourable for the cultivation of walnut trees (*Juglans* sp.), olive trees (*Olea* sp.), cherry trees (*Prunus* sp.), apple (*Malus* sp.), dogwood trees (*Cornus* sp.), pomegranate trees (*Punica* sp.), chestnut trees (*Castanea* sp.) and other crop types. Moreover, the resulting map indicated that the majority of the suitable sites for cultivation were considered favourable for growing walnut trees (24.9%), followed by cherry trees (19.6%) and olive trees (12.1%). Proposing the most suitable cultivations within the study area contributes to forest policy planning and promotes the sustainable development of mountainous less favoured areas, leading to a more rational management of natural resources, a raised awareness of environmental protection, the maintenance of the local population and income enhancement through the production of high quality crops and sustainable yields.

Keywords: forest policy; remote sensing; sustainable yield; planning; regional development; Greece; Pieria Prefecture; walnut; olive; cherry

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1. Introduction

The increased need for natural resources in the 21st century, due to the increased food and fiber demand of the rapidly growing world population, has stressed the importance of the limitation of inappropriate land use in order to achieve the maximization of agricultural production [1]. To this end, the identification of optimal cultivation sites for crops, especially in less favoured areas (LFAs), is considered of utmost importance since it can be utilized in the implementation of policies that will aid in achieving this goal.

Therefore, the sustainable development of LFAs has been a priority issue for the European Union [2] since 2010 because such areas have specific social and economic disadvantages that may lead to the abandonment of agricultural land, especially in mountainous areas [3]. Thus, LFAs need development strategies that take into consideration the special characteristics of these areas and help in mitigating poverty [4]. The farmers in mountainous LFAs seek alternatives in order to increase their income and improve their well-being [5–8]. Tree crop cultivations were mentioned as a sound alternative for the replacement of tobacco cultivation within the framework of the Common Agricultural Policy of the European Union [9].

Furthermore, the forest sector is recognized as a crucial factor for the sustainable development of agricultural areas, creating new job opportunities and improving the living conditions of local people [10]. In order to achieve sustainable development in rural areas, the government and local community should compromise on their preferences in the selection of suitable tree plantations [11]. The creation of employment opportunities is particularly important for mountainous LFAs because it contributes to the maintenance of the rural population [12].

Decision making at the government level affects the vitality of forests [13], although the prediction of future trends is often uncertain [14]. Apart from the traditional methods of planning, such as "scenario development", forest policy uses methods and tools that combine available technology such as Geographical Information Systems (GIS) [15], which have a wide range of applications in forestry, agriculture, climatology and meteorology [16].

Sustainable development in rural areas is strongly related to the selection of crops that have the best adaptation to local climatic and soil conditions [17]. The location of cultivations is of key importance since it affects the productivity and thus cultivation objectives, while proper planning can lead to sustainable systems [18]. Site selection for agricultural products is essential for sustainable agriculture because it is important for the successful growth of the products [19]. Furthermore, zoning is a tool broadly used in the environmental sector, while GIS techniques can solve land allocation problems [20].

GIS are broadly used in modern agriculture, farming and land management [21]. Shadeed et al. [22] developed a suitability map to optimally utilize the available land to achieve best agricultural production. Ali et al. [23] assessed the land use suitability for rubber cultivation in Thailand using GIS, and producing a suitability map. Thompson et al. [24] used a spatial modelling approach to identify the location of favourable habitats for white walnut (*Juglans cinerea* L.) trees and considered as variables, among others, topographic and geological conditions of the study area, Mammoth Cave National Park, in Kentucky, USA. Falasca et al. [25] delineated an agroclimatic zoning model to determine potential growing areas for macaw palm (*Acrocomia aculeata*) in Argentina. Martins et al. [26] used GIS and environmental modelling in order to determine the potential cultivation areas for native tree species of high commercial value in Brazil. Abdelfattah and Kumar [27] developed a web-based GIS that takes into consideration soil information in the United Arab Emirates and can be applied in agricultural land use planning. Roșca et al. [28] used GIS techniques of spatial analysis along with land capability classification in order to a provide a land favourability map of tree crop cultivations. Land suitability classification helps local farmers select the suitable sites and species for different soils in an area [29].

The production of maps is a decision-making method that contributes to integrated rural landscape planning and forest management [30], to the identification of landscape preferences at a regional level [31] and the evaluation of land suitability [32]. Geographical Information Systems (GIS) are widely used for the creation of thematic maps [33] in agriculture, such as in land evaluation for agricultural crops with the aid of Boolean mapping [34–36], or in combination with remote sensing (RS) imagery [37–39]. For example, Cacayan, Jr. et al. [40] created a suitability map identifying in an accurate manner suitable zones for establishing Small Farm Reservoirs in Agusan del Norte, in the Philippines. Moreover, a recent study in Turkey used GIS to evaluate the land use suitability for wheat production taking into consideration geo-environmental factors [41]. In Greece, Charoulis et al. [42] used GIS techniques for the production of thematic maps in order to help farmers improve their practices in the municipality of Gazi, Crete.

Geospatial analysis with the use of interpolation, and especially the kriging technique, is widely used in forestry for the creation of thematic maps such as soil maps [43,44], climatic maps [45] and forest species distribution maps [46,47]. Moreover, Geographical Information Systems and remote sensing data, along with kriging techniques, were used by Mubarakah and Waeli [48] for the evaluation of soil suitability for wheat cultivations in Iraq.

Geospatial techniques were also used in agroforestry as a policy tool for the development of rural areas [49]. Ellis et al. [50] developed a web-based application for agroforestry planning and tree selection in Alachua Country, Florida, USA. A recent study proposed suitable agroforestry systems as a sustainable choice for the forestation of abandoned agricultural land in a mountainous, less favoured area of Greece [51].

The aim of this paper is to present a simplified methodology, which is based on Boolean algebra, for the selection of suitable cultivations sites for multiple tree crop types, hoping that it will be implemented in the future as a forest policy measure under the scope of sustainable development. A more complex methodology was not preferred because complex problems with too many spatial considerations can become intractable [52]. To this end, climatic, topographic, pedological and geological data layers were processed via a simple set of rules and with the aid of GIS geo-processing routines in order to produce, for each specific tree crop type, the optimum sustainable cultivation sites and therefore assist the local farmers.

2. Study Area and Methodology

This section includes a description of the study area and the methodological approach of the paper.

2.1. The Study Area

The study area is a typical mountainous LFA of Greece, Pierion Municipal Unit, in which agriculture and livestock breeding are the main income sources for local people [53], along with mountain tourism [54]. The study area is located approximately from 40°13′ N to 40°21′ N longitude and from 22°10′ E to 22°22′ E latitude (WGS 84), and it covers an extent of 41.3 km^2. Pierion Municipal Unit is situated 15 km west of the city of Katerini and 65 km southwest of the city of Thessaloniki and administratively belongs to the Municipality of Katerini, in Pieria Prefecture. Pierion Municipal Unit consists of three municipal communities: Vria, Ritini and Elatochori (Figure 1).

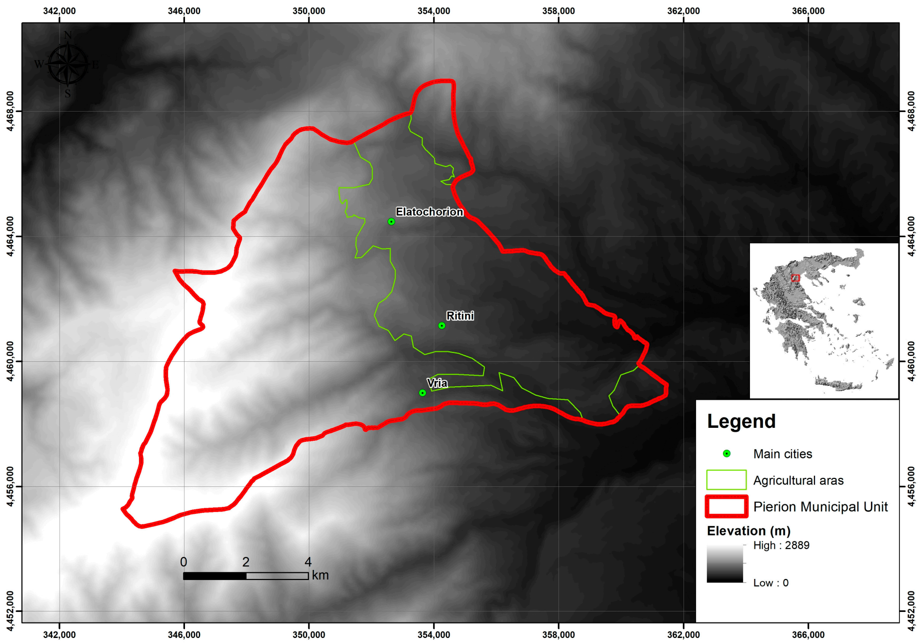

Figure 1. Location of the study area (Pierion Municipal Unit), which belongs to the Municipality of Katerini, in Pieria Prefecture of Greece.

Tobacco cultivation used to be the main source of income for local farmers, but in the last years, a turn to tree crop cultivation has been observed, although a strategic plan for the sustainable development of rural areas in Greece is missing [6]. Tree crop cultivations that adapt well in the study area and are therefore preferred by local farmers are walnut trees, olive trees, dogwood trees, pomegranate trees, apple trees, cherry trees [6].

2.2. Methodology

The methodology involves the delineation of suitable tree crop cultivation sites for walnuts, olives, cherries, apples, dogwoods, pomegranates and chestnuts. Moreover, chokeberries were included as a pilot cultivation and aromatic plants were also examined as an alternative annual cultivation instead of tobacco. Furthermore, truffle cultivation was included as a lucrative solution for suitable areas.

To this end, the factors of geology, topography, pedology and climatology were taken into account, while the data layers that were employed involved the spatial distribution within the study area of: (1) geology, (2) elevation, (3) slope angle, (4) slope aspect, (5) soil pH, (6) total annual rainfall and (7) annual mean temperature (Table 1).

Table 1. Datasets that were employed in the delineation of suitable tree crop cultivation sites.

Data Layer	Scale/Spatial Resolution	Source
Geology	1:50,000	I.G.M.E. geological maps (sheets: Livadion, Velventos, Kolindros and Kontariotissa–Litochoro)
Elevation	25 m	EU-DEM
Slope angle	25 m	EU-DEM
Slope aspect	25 m	EU-DEM
Soil pH	25 m	Field soil sampling
Total annual rainfall	825 m × 825 m	WorldClim
Annual mean temperature	825 m × 825 m	WorldClim

Each data layer was converted into a vector file with the aid of GIS and according to criteria, which were established on the basis of current literature, Boolean algebra GIS tools were employed in order to determine conjunctions between vector files (Figure 2) [34–36]. The aforementioned conjunctions indicated the suitable tree crop sites for each cultivation, and in the case where two or more cultivations were equally suitable for the same site, the area in question was appointed to the cultivation that was considered as more important [6].

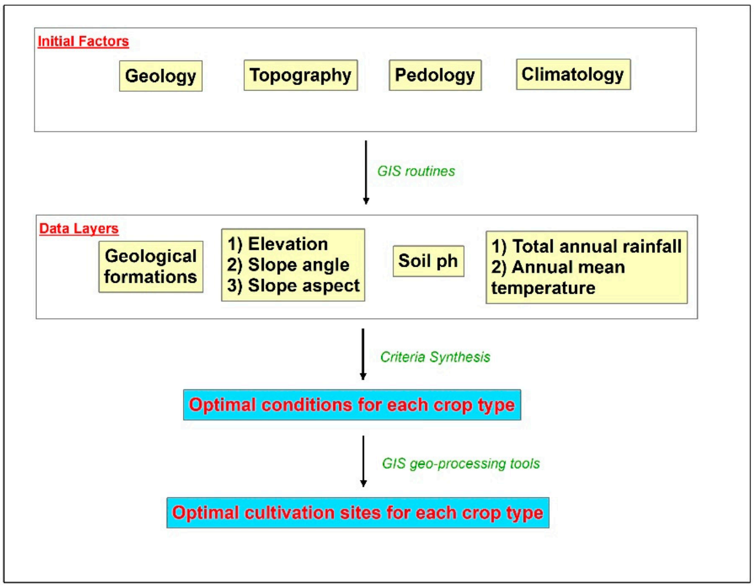

Figure 2. General workflow of the methodology. Initial factors and data layers, written in red (colour) and underlined, indicate the initial sources and the corresponding data layers that were compiled and have been individually placed within yellow coloured squares. Moreover, within blue coloured squares and written in red are the resulting criteria and maps produced via the suggested methodology. Finally, the procedures followed to proceed through the different stages of the methodology are presented in green (colour) and written in Italics.

2.3. Geology

The geology data layer was compiled with the aid of the I.G.M.E. (Institute of Geology and Mineral Exploration) geological maps at a scale of 1:50,000 (sheets: Livadion, Velventos, Kolindros and Kontariotissa–Litochoro) (Figure 3).

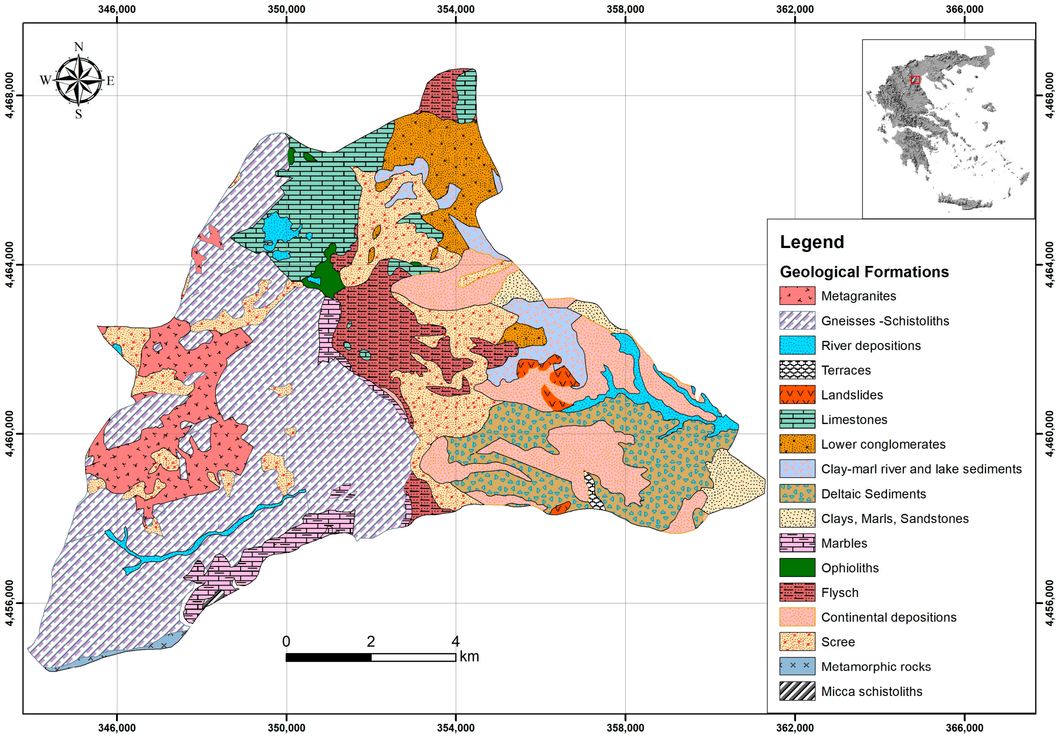

Figure 3. Geological formations map of the study area (Pierion Municipal Unit), which belongs to the Municipality of Katerini, in Pieria Prefecture of Greece.

It can be observed that gneiss and schist are the main geological formations in the study area, but they are situated in the west part of Pierion Municipal Unit, where the Pieria mountain is located, and therefore no farm lands occur. The dominant geological formations in the east part of Pierion Municipal Unit, where agricultural land is mainly found, are: (1) scree, (2) continental depositions, (3) deltaic sediments, (4) clays, stones and marl sands, and (5) lower conglomerates. Limestone formations are found in the north part; while flysch formations are located in the central part of the study area (Figure 3).

The knowledge of the geological background is of key importance, as some cultivations do not thrive on certain geological formations. Chestnut trees, for example, do not grow readily on limestone bedrock [55] because the absorption of soil nutrients is prevented. Other cultivations do not have growth issues on specific bedrock. On the other hand, some cultivations grow better on certain geological formations, for example, walnut trees on limestone bedrock [56].

2.4. Topography

2.4.1. Elevation

The data layer of elevation was derived from EU-DEM, which is the Digital Surface Model (DSM) of European Environment Agency (EEA) members and cooperating countries, and represents the first surface as illuminated by the sensors. It is a hybrid product based on SRTM and ASTER GDEM data fused by a weighted averaging approach [57]. Its horizontal spatial resolution is 1 arc second (approximately 25 m), while its absolute and relative vertical accuracy are 3.6 m and 5.3 m, respectively [58].

Farm lands in the study area are located in areas where elevation ranges from about 150 m to about 1000 m (Figure 4).

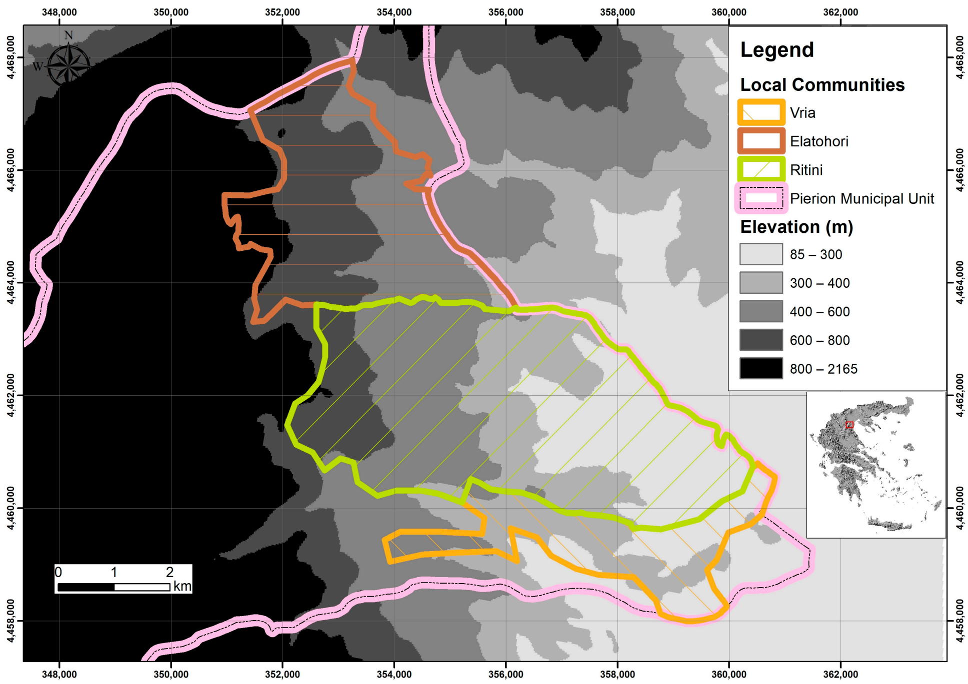

Figure 4. Map indicating the spatial distribution of elevation values of the study area (Pierion Municipal Unit), which belongs to the Municipality of Katerini, in Pieria Prefecture of Greece.

Moreover, the study area was divided into four elevation zones: (1) Zone 1—below 400 m, (2) Zone 2—from 401 to 600 m, (3) Zone 3—from 601–800 m, (4) Zone 4—above 800 m. The most suitable cultivations for each elevation zone are presented in Table 2.

Table 2. Altitude zones in the study area.

Zone	Elevation	Cultivations
Zone 1 (Vria, Ritini)	<400 m	Olives
Zone 2 (Vria, Ritini, Elatochori)	401–600 m	Cherries, Dogwoods, Pomegranates
Zone 3 (Ritini, Elatochori)	601–800 m	Apples, Walnuts, Chestnuts
Zone 4 (Elatochori)	>800 m	Aromatic Plants

Some cultivations are ideal for semi-mountainous and mountainous regions because their production sites require sufficiently cold and long winters: for example walnuts [59], dogwoods [60,61], apples [62] and cherries [63]. Chestnut trees are also usually cultivated in mountain regions [64,65], especially in Greece [66]. Aromatic plants can also be cultivated in high elevation areas, for example, Greek mountain tea (*Sideritis* spp.), which thrives at high altitudes [67].

2.4.2. Slope Angle

The data layer of slope angle, which is very important for the growth of certain crop types, was derived from EU-DEM via the use of GIS routines.

Therefore, more tree crop cultivations, as with all cultivations, show better growth on farm lands (soils) with gentle or small slopes below 30%. They can also be cultivated in soils with slopes above 30% under certain circumstances, while the cultivation of trees is not recommended on steep slopes (above 45%). In the Mediterranean basin, olive groves are mainly located on sloping terraced lands [68].

Most agricultural areas in the study area are characterized by gentle slopes, and are therefore suitable for tree crop cultivation. On the other hand, areas with steep slopes (above 45%) are unsuitable for cultivation (Figure 5).

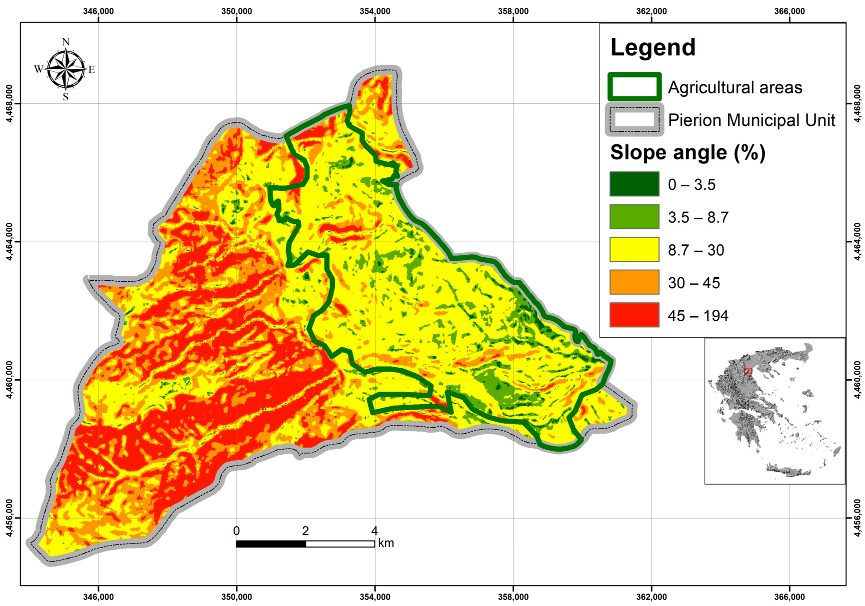

Figure 5. Spatial distribution of slope angle values in the study area (Pierion Municipal Unit), which belongs to the Municipality of Katerini, in Pieria Prefecture of Greece.

2.4.3. Slope Aspect

Slope aspect is a factor that is very influential regarding specific crop types. In the research procedure that is described in this paper, the data layer of slope aspect was derived from EU-DEM via the use of GIS routines.

Specifically, the slope aspect of agricultural areas affects the productivity of cultivations. For instance, truffle cultivation has better and higher production in areas with south or southwest orientation (slope aspect), where truffle trees have better sun exposure [69].

South and southeast slope aspects are mostly dominant in the study area, illustrated with green colours in Figure 6, followed by northeast, east and north slope aspects. West, southwest and northwest aspects are the least observed for the agricultural areas of the study area.

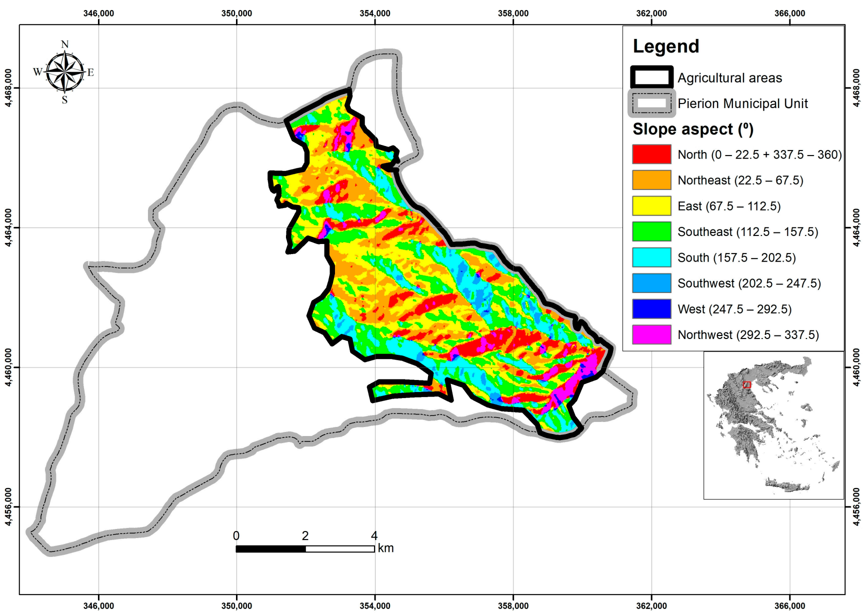

Figure 6. Spatial distribution of slope aspects in the study area (Pierion Municipal Unit), which belongs to the Municipality of Katerini, in Pieria Prefecture of Greece.

2.5. Pedology

Soil conditions (soil pH, soil texture, etc.) affect tree crop cultivations. Soil in the study area has low, almost zero salinity. Therefore, fruit tree cultivations benefit because they are salinity sensitive [70].

A soil pH map (Figure 7) was produced by applying the interpolation kriging method to 50 soil samples that were collected and analysed from farmlands in the study area. Interpolation was used for the compilation of the pedology data layer, and more specifically, the "kriging" technique, which is the most common technique according to the literature, and its accuracy depends on the number of spatial observations [71–73].

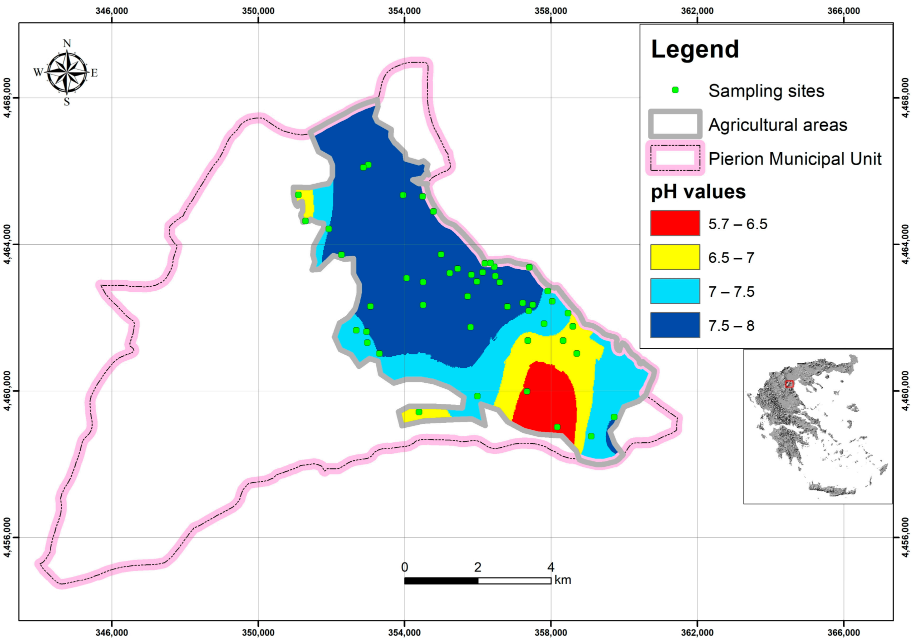

Figure 7. Map depicting the spatial distribution of pH values and the sampling sites in the study area (Pierion Municipal Unit), which belongs to the Municipality of Katerini, in Pieria Prefecture of Greece.

According to the analysis of the samples, the most acid soils were located in the local community of Vria, while the most alkaline soils were found in the local community of Elatohori. Moreover, in the local community of Ritini there was a wide range of pH values, from medium acid (under 6.5 pH) in the south part to medium alkaline (above 6.5 pH) in the northern part. The vast majority of soils in the study area were alkaline with pH values above 7, ranging from slightly alkaline to medium alkaline. These pH values are suitable for the proposed cultivations in the study area [6]. For example, chestnut, which is a typical acidophilic tree [74], can be cultivated in the south part of the study area, where more acid soils are found. On the other hand, walnuts prefer alkaline soils with pH higher than 7, up to 7.6 [6,59]. Truffles also prefer alkaline soils within a pH range from 7.4 to 8.2 [75].

2.6. Climatology

Climatic conditions severely affect tree crop cultivations [76]. Average, minimum and maximum temperatures, rainfalls and their distribution, relative humidity are some of the factors that affect the adjustment and thus the productivity of cultivations in an area. The effect of climatic conditions in the selection of the optimum sustainable sites for tree crop cultivation contributes to water conservation, as the cultivations' needs for water are taken into consideration.

2.6.1. Rainfall

Rainfall is a crucial factor that affects cultivations. Water demanding cultivations such as walnuts [77] and chestnuts [78] are mainly situated in areas with average annual rainfall more than 500 mm and up to 800 mm [79,80]. Moreover, pomegranates are negatively affected by rainfall during the period of fruit maturity, as the fruit splits [81].

The WorldClim database provided raw data for compiling the annual total rainfall layer [82]. The raw data are available in the form of a 30 s by 30 s grid (approximately 824 by 824 m), which covers the climatological period from 1970 to 2000 and involves monthly precipitation totals [82]. Map algebra was used to sum all 12 monthly precipitation totals and construct the total annual precipitation layer. Subsequently, the aforementioned rainfall layer was converted to a point shapefile, from which the final rainfall data layer, with a spatial resolution of 25 m, was derived. The universal kriging spatial interpolation method was employed in order to downscale the original WorldClim layer (824 × 824 m spatial resolution) into the layer that would be used in the current methodology (25 × 25 m spatial resolution) [83]. The interpolated values were the total annual precipitation values obtained at each point of the original WorldClim grid. The auxiliary variables were slope aspect, elevation, slope angle and distance from the sea. EU-DEM provided data for the compilation of the elevation, slope aspect and slope angle data layers. Furthermore, by employing proximity analysis routines, the distance from the sea data layer was compiled with a grid resolution of 25 m.

The study area is characterized by high annual rainfall, a fact that allows even the most water-demanding cultivations (walnuts and chestnuts) to grow productively. The minimum annual rainfall is 446 mm, and it is observed in the eastern part of Pierion Municipal Unit. The annual rainfall increases towards the western part of the study area, where the mountain Pieria is located (Figure 8).

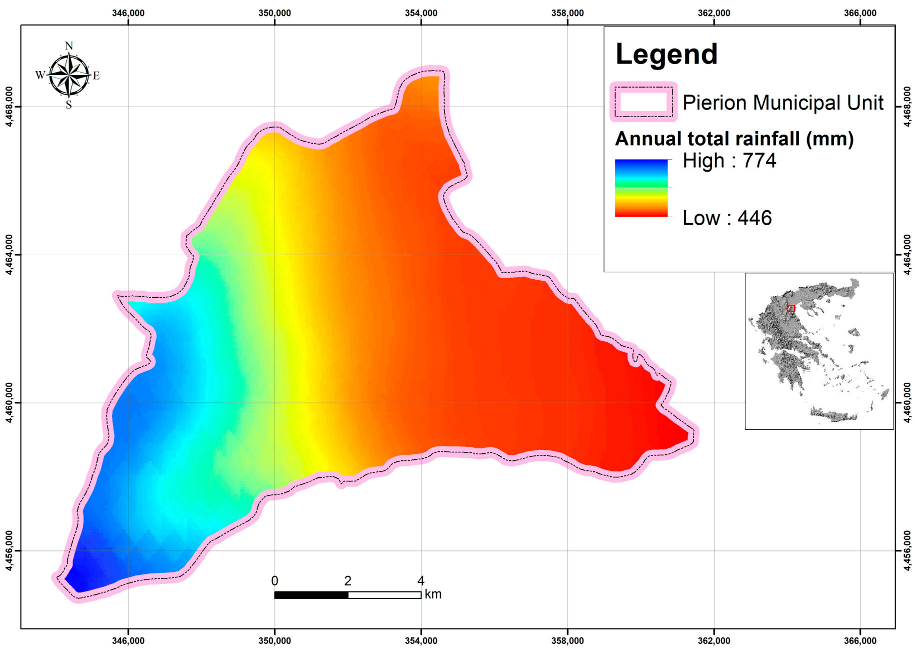

Figure 8. Spatial distribution of annual total rainfall in the study area (Pierion Municipal Unit), which belongs to the Municipality of Katerini, in Pieria Prefecture of Greece.

2.6.2. Temperature

Air temperature is another factor that affects tree crop cultivations. Some fruit trees thrive in cold climates, such as apple trees [62], cherry trees [84], dogwoods [60,61] and black chokeberry trees [85], while others do not, such as olive trees [86,87] that can be found at the lower altitudes of the study area where the average air temperature is relatively high.

The compilation of the annual mean temperature data layer was similar to the procedure that was followed in order to produce the annual total rainfall. Therefore, the WorldClim database provided raw data for the compilation of the annual mean temperature data layer [82]. The raw data are available in the form of a 30 s by 30 s grid (approximately 824 by 824 m), which covers the climatological period from 1970 to 2000 and involves monthly average temperature values [82]. Map algebra was employed to sum all 12 monthly average temperature layers and construct the annual mean temperature layer. Subsequently, the derived temperature layer was converted to a point shapefile, from which the final temperature data layer, with a spatial resolution of 25 m, was produced. The universal kriging spatial interpolation method was employed in order to downscale the original WorldClim layer (824 × 824 m spatial resolution) into the layer that would be used in the current methodology (25 × 25 m grid resolution) [83]. The interpolated values were the annual mean temperature values obtained at each point of the original WorldClim grid. The auxiliary variables were slope aspect, elevation, slope angle and large water bodies. EU-DEM provided data for the compilation of the elevation, slope aspect and slope angle data layers. Furthermore, by employing proximity analysis routines, the distance from large water bodies' data layer was compiled with a grid resolution of 25 m.

Areas with a higher average air temperature are located in the eastern part of the study area, while areas with the lowest average air temperatures are situated in the western part, near mountain Pieria (Figure 9).

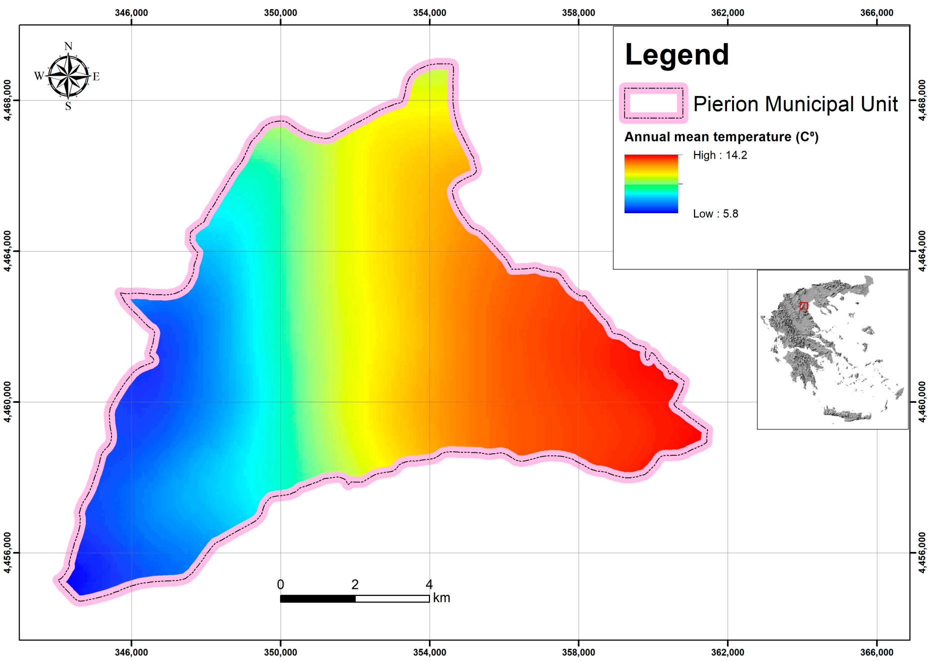

Figure 9. Spatial distribution annual mean temperature in the study area (Pierion Municipal Unit), which belongs to the Municipality of Katerini, in Pieria Prefecture of Greece.

2.7. Optimum Conditions for Each Cultivation

Each of the aforementioned data layers was compiled by taking into account how the spatial distribution of each factor affects tree crop cultivation. Thus, each data layer was classified according to the needs of each cultivation that was affected by the corresponding factor. Consequently, Table 3 was produced in order to sum up all the criteria that can be used in order to determine the most suitable locations for each crop type separately.

Table 3. Synoptic table of the optimal conditions for the cultivation of each crop type.

Crop Type	Criteria (Boolean Algebra Expression)	References
Apples (*Malus* sp.)	(1) Elevation above 400 m AND (∩) (2) Annual total rainfall higher than 450 mm AND (∩) (3) Annual mean temperature below 14 °C	[6,62]
Cherry trees (*Prunus* sp.)	(1) pH = 6–7.5 AND (∩) (2) Annual total rainfall higher than 450 mm AND (∩) (3) Annual mean temperature lower than 15 °C	[6,63,84]
Chestnuts (*Castanea* sp.)	(1) No limestone AND (∩) (2) pH = 5.5–6.5 AND (∩) (3) Elevation higher than 400 m AND (∩) (4) Annual total rainfall higher than 450 mm	[6,55,64–66,74,78,79]
Dogwoods (*Cornus* sp.)	(1) pH = 5.5–7.5 AND (∩) (2) Annual mean temperature lower than 14 °C AND (∩) (3) Annual total rainfall higher than 450 mm	[6,60,61]
Olives (*Olea* sp.)	(1) Elevation below 400 m AND (∩) (2) pH = 6.5–8 AND (∩) (3) Annual mean temperature higher than 10 °C AND (∩) (4) Slope angle 0%–45%	[6,68,86,87]
Pomegranates (*Punica* sp.)	pH = 6.5–7.5	[6]
Truffles(*Tuber* sp.)	(1) pH = 7.4–8.2 AND (∩) (2) Slope aspect S or SW	[6,69,75]
Walnuts (*Juglans* sp.)	(1) On limestone AND (∩) (2) pH = 7.2–7.6 AND (∩) (3) Annual total rainfall higher than 450 mm	[6,56,59,77,80]
Black Chokeberries (*Aronia* sp.)	(1)pH = 5–8 AND (∩) (2) Annual mean temperature lower than 14 °C	[6,85]
Aromatic Plants (e.g., *Sideritis* sp., *Origanum* sp., *Thymus* sp., *Lavandula* sp.)	Elevation higher than 800 m	[6,67]

The conjunctions between the classes of the data layers, which are presented as Boolean algebra expressions in Table 3, indicate the spatial distribution of intersecting favourable conditions that designate a location as suitable for a certain type of tree crop cultivation. For example, the suitable sites for walnuts were determined by conjoining areas of limestone formations, from the geology data layer, with areas of pH values that ranged from 7.2 to 7.6, which were derived from the corresponding classes of the pedology data layer, and with areas of more than 450 mm annual total rainfall, which were derived from the corresponding classes of the rainfall data layer. Likewise, sites suitable for black chokeberry tree crop cultivation were delineated by conjoining areas with pH values that ranged from 5 to 8, which were derived from the corresponding classes of the pedology data layer, with areas of annual mean temperature lower than 14 °C, which were derived from the corresponding classes of the temperature data layer. Furthermore, if two or more cultivations were equally suitable for the same site, the area in question was appointed to the cultivation that was considered more important. For this purpose, the order of importance that was followed by the authors was the following (from more important to least important): (1) walnut trees (*Juglans* sp.), (2) olive trees (*Olea* sp.), (3) cherry trees (*Prunus* sp.), (4) apple trees (*Malus* sp.), (5) dogwood trees (*Cornus* sp.), (6) pomegranate trees (*Punica* sp.), (7) chestnut trees (*Castanea* sp.), (8) chokeberry trees (*Aronia* sp.), (9) aromatic plants (e.g., *Sideritis* sp., *Origanum* sp., *Thymus* sp., *Lavandula* sp., etc.) and (10) truffles (*Tuber* sp.) [6].

3. Results

The final map of the optimum sites for tree crop cultivations in the study area (Figure 10) was produced by combining all the aforementioned thematic maps. All factors that affect the cultivations such as elevation, climatic conditions, geology, slope angle, slope aspect and soil conditions were taken into consideration for the creation of the final map. The final map depicts the optimum sites for the cultivations proposed for the study area: olives, apples, cherries, walnuts, dogwoods, pomegranates, chestnuts and black chokeberries. Moreover, the final map illustrates the optimum sites for truffle cultivation and the cultivation of aromatic plants, which are good alternatives for local farmers who want to replace the traditional tobacco cultivation.

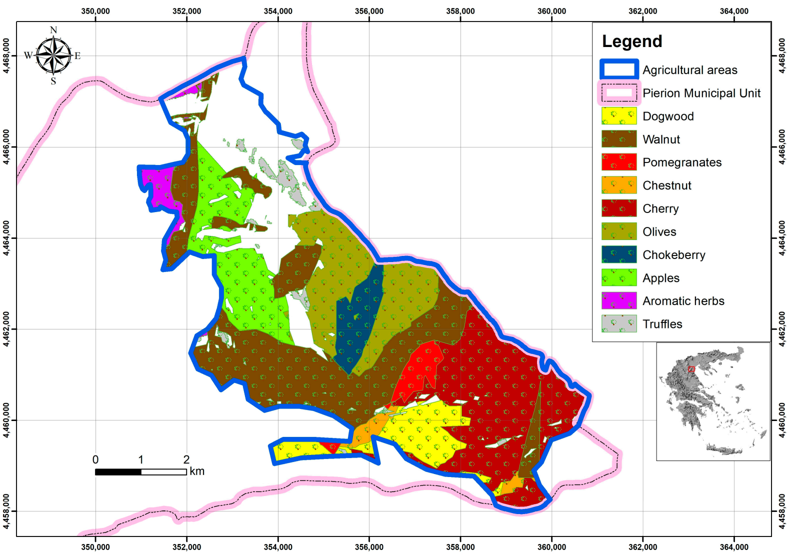

Figure 10. Map of optimum sites for tree crop cultivations in the study area.

Walnut trees, olive trees, cherry trees and apple trees are the best-adjusted cultivations in the special conditions of the study area, followed by dogwood trees, pomegranate trees and chestnut trees. Black chokeberry (*Aronia melanocarpa*) trees could be tested as pilot cultivations in soils unsuitable for other cultivations, as *Aronia melanocarpa* is a species that can be cultivated in almost any climatic and soil conditions [85]. Truffle can also be cultivated on some farm lands with specific characteristics, such as alkaline soil pH > 7 [75] and south or southwest slope aspects [69]. Aromatic plants are an excellent choice for high altitudes (above 800 m) [67] on sites that are unsuitable for tree crop cultivation. They can also be cultivated on farm lands for which no suitable tree crop cultivation has been proposed; these areas are illustrated in the final map (Figure 10) as blank (no colour was selected). Additionally, 7.2 km^2 (17.4%) of the study area was unsuitable for any cultivation crop, according to the criteria that were applied. Furthermore, the areas that are covered by each cultivation are presented in Table 4. It can be observed that the largest part of the agricultural areas of the Pierion Municipal Unit is suggested to be cultivated with walnut trees, followed by cherry trees, olive trees and apple trees. On the other hand, chestnuts and pomegranates are the least suggested cultivations for the study area. Truffles, aromatic plants and black chokeberries are recommended only for certain sites under specific conditions. Moreover, from the resulting map (Figure 10), it can be observed that the southeast parts of the agricultural areas in the Pierion Municipal Unit are more suitable for cherry tree cultivation, while the central parts of the aforementioned area are more suitable for olive and walnut tree cultivation. Finally, favourable conditions for apple tree and aromatic plant cultivations can be found in the northwest parts of the study area.

Table 4. Area covered by each of the suggested crop types.

Crop Type	Area (km^2)	Percentage (%)
Chestnut trees	0.5	1.2
Walnut trees	10.3	24.9
Pomegranate trees	0.8	1.9
Apple trees	3.9	9.4
Olive trees	5.0	12.1
Dogwood trees	2.5	6.1
Truffles	0.6	1.5
Cherry trees	8.1	19.6
Black chokeberry trees	1.5	3.6
Aromatic plants	0.9	2.2
Unsuitable	7.2	17.4

4. Discussion

Selection of the most suitable tree crop cultivations contributes to the sustainable development of mountainous less favoured areas (LFAs) in Greece. The vast majority of LFAs in Greece are situated in semi-mountainous and mountainous zones [88]. Forest policy can significantly contribute to issues concerning strategy planning in the wider forest and agri-environmental sector [6,51,53]. The proposed species are well-adjusted in semi-mountainous and mountainous areas, are water saving, and can be used in the production of crops of high nutritional value, as well as in timber production [6]. Moreover, they effectively contribute to the protection against climate change, a primary target for the European Union [89].

The selection of suitable cultivations with this procedure focuses on the limitation of the dominant practice so far in Greece, where the establishment of a cultivation in an area is based only on economic benefits and on the implementation of non-environmentally friendly practices such as overwatering and overfertilization. It also focuses on farmlands that remain unexploited or are cultivated with tobacco. Tobacco is considered a non-sustainable cultivation because it is labour intensive [90], highly water demanding [91] and causes land degradation [92].

The described process minimizes the risk of the investment, as the productivity of cultivations on suitable sites is increased and the costs for fertilizers and water are reduced [93–95]. Thus, a series of benefits arises: the rational management of natural resources, the increased awareness of farmers on environmental protection issues and the compliance of sustainability principles [96], maintenance of the local population in the area through socioeconomic incentives [97], income enhancement and the production of crops of high nutritional value (e.g., walnuts, olives, dogwood berries, pomegranates, chestnuts, etc.) [98].

Regarding the methodology that was followed, it was attempted to delineate the optimum cultivation sites for ten different crop types, and therefore, data layers were employed that were easily accessible and involved limitations for each one of the examined crop types. Although there are neither uniquely established optimum cultivation conditions for each of the utilized crop types nor sufficient studies conducted in this field for the study area, criteria can be extracted from both the literature and empiric rules and observations. Moreover, the importance of the crop types was established according to the optimum needs in terms of crop yields for the study area, and this was based partly on experts' opinions and partly on the current literature [6].

Future studies could include agroforestry systems, tree crop cultivations combined with agricultural cultivations on the same piece of land. Suitable agroforestry systems for the study area include the combination of all suitable tree crop cultivations presented in this study with suitable agricultural cultivations, such as corn (*Zea mais*) and medick (*Medicago* sp.) [51]. Future studies could also further improve the employed kriging techniques.

5. Conclusions

To sum up, this study aimed to determine suitable sites for the cultivation of 10 different crop types. To this end, topographical, climatic, geological and pedological criteria were employed in order to produce a suitability map that would indicate the optimum cultivation sites for each crop type. The results indicated that the vast majority of the study area was suitable for cultivating any of the studied crop types and only a small part of it was determined as unsuitable for all of the examined crop types. Furthermore, most of the suitable areas were determined as suitable for the cultivation of walnut trees, followed by the cultivation of cherry trees and olive trees.

The paper focuses on a typical mountainous less favoured area (LFA) of Greece, in which the main income sources are agriculture, livestock breeding and mountain tourism. The study area faces the same problem as most LFAs in Greece, the lack of a strategic plan for the sustainable development of rural areas. The scientific innovation of the paper is that it aims to change the existing practice in Greece, where farmers mostly choose their cultivations based on the economic profit, ignoring the consequences on the other two sustainability pillars: environmental protection and social equity. The search for optimum sustainable sites for tree crop cultivations guarantees, apart from economic benefits, environmental benefits as a result of the reduction in fertilizing and watering, as well as social benefits as the farmers will be motivated to remain in the area. Moreover, it provides a sustainable alternative instead of tobacco cultivation, focusing on unexploited agricultural lands.

The methodological approach could be used in other mountainous less favoured areas with similar characteristics, in Greece and other Mediterranean countries, such as Cyprus, Italy, Spain, Turkey, etc., taking into consideration the special conditions of the countries and including more tree crop cultivations that are suitable for each study area. Moreover, the findings of this study may serve in forest policy planning by contributing to the establishment of measures that will prevent inappropriate land use and aid in the maximization of agricultural yield.

The criteria that were followed in order to determine the suitability sites were based on both the literature and empiric rules, since there were no available studies on this field, that have been conducted for the study area. Additionally, since the optimum selection of cultivation sites is of paramount importance for the maximization of agricultural yield, this study can be used as a guide for applying simple rules to determine optimum cultivation sites for crop types in an area that lacks specific studies that would help the local farmers. Finally, by conducting more studies on the conditions that are favourable for each crop type, the criteria might be further refined, and this methodology might be able to produce more accurate and detailed results.

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