Article

Identification of Optimal Mechanization Processes for Harvesting Hazelnuts Based on Geospatial Technologies in Sicily (Southern Italy)

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Abstract: Sicily is a region located in the southern Italy. Its typical Mediterranean landscape is
appreciated due to its high biodiversity. Specifically, hazelnut plantations have adapted in a definite
area in Sicily (the Nebroidi park) due to specific morphological and climatic characteristics. However,
many of these plantations are not used today due to adverse conditions, both to collect hazelnuts
and to reach hazel groves. Though a geospatial analysis, the present paper aims to identify which
hazelnut contexts can be actively used for agricultural, economic (e.g., introduction of a circular
economy) and energetic purposes (to establish a potential agro-energetic district). The examination
revealed the most suitable areas giving several criteria (e.g., slope, road system), ensuring an effective
cultivation and consequent harvesting of hazelnuts and (ii) providing security for the operators since
many of hazelnut plants are placed in very sloped contexts that are difficult to reach by traditional
machines. In this sense, this paper also suggests optimal mechanization processes for harvesting
hazelnuts in this part of Sicily.

Keywords: hazelnuts; spatial analysis; mechanization processes; precision farming; rural
landscape; Sicily

1. Introduction

The rural landscapes of Mediterranean Europe are characterized by their peculiar crops, whose
agricultural practices have led to different land use changes [1]. In recent years, there has been a strong
abandonment of agricultural areas [2,3], supporting a consequent reforestation development [1,4].

Hazelnuts represent ones of most produced nut crops in the Mediterranean contexts, as in Italy [5],
since as agricultural products have relevant nutritional and economic value [6]. Given their profitability,
they are also grown on unsuitable ground, due to the absence of land use policies (as in Langhe region
in Italy) [2,7]. For example, Turkey imposed specific regulations for cultivating hazelnuts in given
areas, where the maximum elevation is 750 m, the slope is more than 6% and IV or upper class of
LCC [8]. According to such government regulations, potential hazelnut areas can be mapped with
specific criteria (e.g., slope, elevation, and land use–land cover) using GIS technology [9]. Consequently,
their detection may be useful to observe landscape changes, providing greater support to national
and international institutions in the assessment of rural agriculture policies [10] and their latent
consequences on local society, landscape, and production [11–13].

Defining hazelnut areas is possible through maps and satellite images by advanced computer
programs such as Geographical Information Systems (GIS) and Remote Sensing (RS) technologies,

which offer benefits in data management and acquisition [6,14]. In recent decades, GIS and RS have been appreciated within rural applications linked to resources at several spatial scales [9,15]. GIS presents a suitable tool for processing, analyzing, and collecting spatial information [7,16,17]. Spatial analysis reveals elevation, aspect, slope, and soil data using GIS methods and even investigates environmental situations, soil attributes, and topographic changes [6,9,18]. From RS technologies, land cover classification is regularly achieved by a multi-class scenery and supervised arrangement of textural or spectral characteristics at pixel level [19,20]. Remote sensing imagery permits to provide data about hazelnuts from satellite images [21], which can be then integrated to other database in GIS with the aim of securing sustainable development of rural areas [6,22–24]. Therefore, through Geographical Information Systems (GIS) and remote sensing with multi-temporal high-resolution satellite data, land use changes, vegetation cover, soil degradation, and further issues can be monitored integrally [25,26].

Remote identification of hazelnuts is not reasonably straightforward [2,7,27,28]. However, it is necessary (i) to optimize harvesting methods and (ii) to distinguish rural landscape dynamics and socio-economic and land use changes to achieve sustainable development [29,30]. Their detection usually takes place through a visual interpretation of very high resolution remote sensing imagery to exploit spectral and textural features, due to the absence of an automated method [20]. However, few studies have focused on mapping hazel groves with high resolution imagery [7,20,31–33]. Vegetation variables appear continuous and difficult to distinguish, e.g., biomass, fraction of vegetation cover, or leaf area index [28,34]. For instance, NDVI values appear very close for hazel groves and further woody vegetation [20]. In fact, it is difficult distinguishing hazelnuts from forest areas and other similar crops (such as olives) that are also typical of the Mediterranean landscape [35]. Their identification from other areas can decrease the inventory expenses by saving money and time [35]. The existence of vegetation maps, performed through Geographic Information Systems (GIS), can be useful for both qualitative and quantitative assessments of natural resources in a definite context [36–40].

The importance of having analytical parameters is essential to find hazelnut plants. The latter are usually located at an altitude of 500 and 1000 m [41]. Their typical altimetry is motivated by the degree of humidity and climate, with a slope between 6% and 30% [6]. Furthermore, the cultivation of hazelnuts is not recommended on steep slopes, since they are not able to prevent and hinder potential soil erosion processes [42,43].

Hazelnut production is frequently characterized by irregular plantations and inconstant density, from steep slopes and rough terrain environments [44]. There are several mechanization methods for collecting hazelnuts, aiming to rationalize costs and harvest production using appropriate existing technologies [45,46]. Several research activities have been launched to assess the collection of hazelnuts, minimizing the risks for the operators in the field (e.g., risk of overturning) [44]. Hazelnuts are usually planted in rows along which herbicides are distributed during the year on the herbaceous vegetation for improving mechanical operation during the harvest [47]. The major problem during the hazelnut collection concerns the situations of high slopes and terraces in addition to the risk of roll-over problems [44]. Furthermore, the intense hazelnut harvesting can lead to negative consequences (e.g., soil erosion) [47] and it is therefore necessary to evaluate how to optimize the collection depending on the soil characteristics.

The purpose of this paper is to identify hazelnuts with the aim of proposing strategies and optimizing mechanization systems through geo-spatial technologies. The case study focuses on 10 municipalities in the Sicily region, which are part of the National association of hazelnuts. In these contexts, many hazelnut plantations appear to be woods. Hazelnuts have well-adapted in the Nebrodi mountains [38], but very often are in problematic areas to reach and work in safety. The present paper aims to recognize the areas that really can contribute to the primary sector in economic terms, estimating the potential hazelnut cultivation, ensuring opportunities for cultivation and the security for operators during the harvesting according to the intrinsic characteristics of such context. In this framework, an optimization of collection and mechanization processes, depending

on geo-morphological and territorial characteristics and avoiding possible pollution, was reached. This first examination estimates the biomass obtained from suitable hazelnut plants pruning, as a real solution to produce energy through thermo-chemical processes, i.e., combustion, gasification, and pyrolysis [48]. Finally, the work aims to suggest the consolidation of an agro-energetic district in this context. The latter provides several benefits, as it strengthens the local economy linked to the cultivation of hazelnuts and can start a reality based on the circular economy with the purpose of re-using agricultural residues for energy purposes.

2. Materials and Methods

2.1. Context of Study

Sicily is a Southern Italian region with many forests and fields designed for agricultural activities. Among these, hazelnuts have settled as one of the most visible crops in the north-eastern part of Sicily (along the Nebrodi mountains), given the confident morphological and climatic features [38]. The cultivation of hazelnuts in Sicily covers a surface area of 16,482 hectares, producing each year around 204,306 quintals. The diffusion of hazelnut trees in this context took place in 1890, after the crisis of gelsiculture. Today, thanks to their ease of adaptation, dense root system and profitable productivity, hazelnuts are the predominant yield of the Nebrodi agrarian landscape [38]. In this regard, the municipalities of the province of Messina of Castell'Umberto, Montalbano Elicona, Sant'Angelo di Brolo, Raccuja, Santa Domenica Vittoria, San Piero Patti, San Salvatore Fitalia, Sinagra, Tortorici and Ucria are part of the National Association of Hazel Towns ('Associazione Nazionale Città della Nocciola'), representing the region of Sicily.

2.2. Data Analysis and Materials

ESRI ArcGIS software was used to integrate data and accomplish spatial analysis [6]. GIS technology is decisive to spatial surveys for examining the context of the study. As computer-based system, it allows to capture, storage, recovery, analyze and display geographic data [17]. In this study, GIS techniques were used to overlay maps (vegetation map of Sicily, Corine Land Cover (CLC), and other geospatial data, as well as road system), to make elaborations examining where the hazelnuts are located and to hypothesize mechanization processes focusing on some of their morphological characteristics: DTM, slope, aspect and curvature. The National Terrain Model (DTM) map is the representation of the interpolation of orographic data from the map of the Military Geographic Institute. The resulting product is a 20 m regular step matrix, whose elements (pixels) show the values of the quotas. The Slope identifies the maximum rate of change in value from that cell to its neighbors. Principally, the maximum change in elevation over the distance (among the cell and its eight neighbors) finds the steepest downhill descent from the cell. The Curvature displays the shape or curvature of the slope and is calculated by computing the second derivative of the surface. The curvature, parallel to the slope, indicates the direction of maximum slope. A part of a surface can be concave or convex, by looking at the curvature value. It affects the acceleration and deceleration of flow across the surface: (i) a negative value indicates that the surface is upwardly convex at that cell, and flow will be decelerated, (ii) a positive profile indicates that the surface is upwardly concave at that cell, and the flow will be accelerated, and (iii) a value of zero indicates that the surface is linear. As the slope direction, aspect displays the downslope direction of the maximum rate of change in value from each cell to its neighbors. The values of each cell in the output raster designate the compass direction that the surface faces at such location, measured in degrees from 0 (north) to 360 (again north). Having no downslope direction, flat areas assume a value of −1.

The vegetation map was used as the base for the land use. It represents a convenient combination of the vegetal landscape, whose complex diversity reproduces the greatest physiographic, geomorphological, lithological, and bioclimatic variability of this region. In fact, the vegetation map is characterized by 36 phytocoenotic categories. As a result of years of research, it gives a summary

of the widespread phytosociological and cartographic literature in Sicily. It was performed through Geographic Information Systems (GIS) at several scales (1:50,000, 1:25,000, and 1:10,000) and provides both qualitative and quantitative assessments of natural resources [36–40].

The vegetation map of Sicily was prepared at a 1:250,000 scale according several stages: (i) preparation of a GIS project (1:10,000 scale) with an inclusive database and thematic layers with georeferenced materials, (ii) photo-interpretation of the vegetation with satellite images (e.g., Landsat TM), orthophotos and digital data on the Technical Map of Sicily; (iii) validations with other maps, such as land use, vegetation or geology, (iv) validation of the photo-interpretation through field survey and verification, (v) digitization of the outcomes and further data, and (vi) phytosociological classification of the mapped types, categorized by 36 phytocoenotic classes [38]. Therefore, the vegetation map identifies all the existing crops in Sicily in a precise and detailed way. For instance, hazelnuts (identified with the code 202) occupy a surface area of about 9500 hectares.

2.3. Mechanization Framework

The cultivation of hazelnuts is characterized by several factors that make it difficult and dangerous to use mechanization systems for operators, at all stages of cultivation, especially in the harvesting phase. Some of these factors are predominantly irregular plantations, a high degree of acclimatization of the slopes (which also reach 35 degrees), uneven ground conditions, a lack or absence of business and interpersonal viability, presence of obstacles to the passage of machines, and unusual soil management with the abandonment of pruning residues on the ground.

The north-eastern part of Sicily along the Nebrodi mountains has seen the spontaneous diffusion of hazelnuts, which have easily adapted [38]. Despite their potential productivity, hazelnut plants are placed in very problematic environments, especially for the harvest phase, and therefore most of them are abandoned. Traditional vehicles have difficulty reaching these contexts (e.g., steep slopes that make it unsafe for operator intervention). Therefore, the currently-mechanization methodologies are equal to zero. In fact, harvesting is still by hand-picking in the few cultivated areas.

Focusing the prototype tested by [44], the present work suggests using a similar device that is self-propelled and easily transportable for harvesting in areas with poor or absent roads between farms (Figure 1). The device can move even under critical slope circumstances (even up to 30–35%) and overcoming substantial difficulties (e.g., terraces, where can be assemble the harvester to a mini crawler with hydraulic or hydrostatic transmission). In this manner, mechanization can be introduced in principally disadvantaged areas, with consequences in terms of safety for operators and a cost-benefit decrease. In operational stages, however, their prototype collects in a stationary position with the assistance of a suction line, permitting operation on highly sloped surfaces (more than 20%). The prototype tested by [44] is ideal for this Sicilian context, avoiding problems linked to steep slopes and movement among hazelnut groves.

Figure 1. Photo of the small-scale machine for nuts harvesting proposed in the study of [44].

3. Results

By means of a first GIS processing, the municipalities chosen are counted on a surface area of almost 4970 hectares (representing 52% of the hazels in the Sicily region) (Table 1). Comparing the vegetation map with the CLC, the accuracy of the first map was confirmed (Figure 2). While the CLC considered hazelnuts as forests, the vegetation map of the Sicily region highlighted their presence as hazelnuts (code 202). By comparing the two maps, 63% of the hazelnuts identified as "orchards" in CLC, while 22% are categorized as "deciduous forests" in CLC. As a first clarification, the CLC tends to aggregate hazelnuts in the category "orchards". Nonetheless, many fields of hazelnuts (22%) visually appeared as forests.
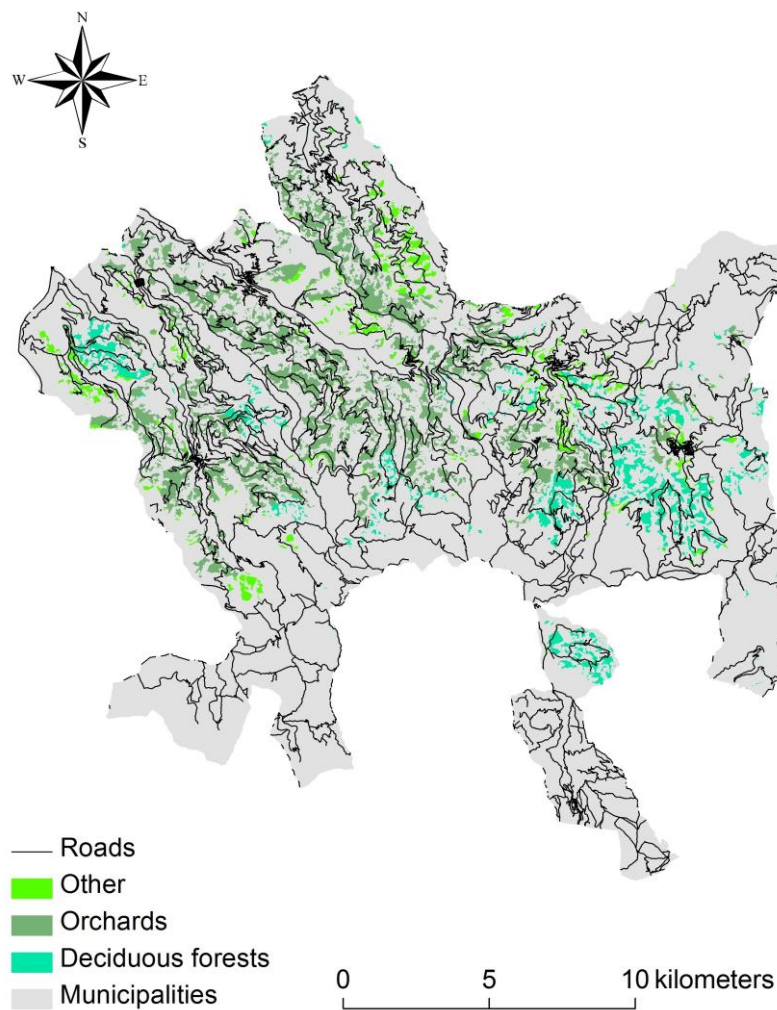

Figure 2. Hazelnut areas identified by the vegetation map of the region of Sicily. Each plot corresponds to the land use observed in CLC. Source: own elaboration.

Table 1. Hectares of hazelnuts belonging to vegetation map overlapped to CLC classes for each municipality.

Hectares of Hazelnuts Belonging to CLC Classes	Continuous Urban Fabric	Discontinuous Urban Fabric	Arable Crops in Non-Irrigated Areas	Orchards and Minor Fruits	Olive Grove	Annual Crops Associated with Permanent Crops	Complex Crop and Systems	Mainly Occupied Areas	Deciduous Forests	Areas with Natural Pasture at High Altitude	Areas Affected by Fires	Total of Hazelnuts
Code of CLC	111	112	211	222	223	241	242	243	311	321	334	
Castell'Umberto		20.88		85.16	17.95				0.24	0.00		124.23
Montalbano Elicona		5.16	4.07	91.99	1.47			35.49	457.65	16.82	0.20	612.85
Raccuja		8.46		315.92	15.40			21.75	25.37	4.64		391.53
San Piero Patti	3.32		7.21	423.81	66.77			91.16	205.15	17.86		815.28
San Salvatore di Fitalia		14.49		65.52	5.07		19.72	2.50	138.41	43.77		289.47
Santa Domenica Vittoria									118.95	0.00		118.95
Sant'Angelo di Brolo	0.22		0.71	471.31	26.53	23.51	2.18	38.21	19.68	82.73		659.21
Sinagra		1.87		455.59	44.39			3.12	1.26	9.75		515.98
Tortorici		11.97	0.47	669.69				0.56	92.44	63.45		838.59
Ucria		7.17		535.19	0.19			1.63	54.85	4.32		603.35
Total	3.54	70.00	12.45	3114.18	177.78	23.51	21.90	194.42	1114.00	243.33	0.20	4969.43
	0%	1%	0%	63%	4%	0%	0%	4%	22%	5%	0%	100%

Source: own elaboration.

Representing 43% of the hazelnuts considered, San Piero Patti and Tortorici are the municipalities that recorded the highest presence of hazel trees within their administrative boundaries. Hazelnuts plants prefer high altitudes (Table 2). In fact, 84% of them can be observed between 500 and 1000 m above sea level (with an average of 755 m by examining municipalities in analysis). Castell'Umberto, San Salvatore di Fitalia, Sant'Angelo di Brolo, and Sinagra are the municipalities that identified a larger percentage of hazelnuts at a moderate altimeter than the others, i.e., between 500 and 750 m. The municipality of Santa Domenica Vittoria demonstrated that 86% of its hazelnuts are above 1000 m, although it recorded, in quantitative terms, a reduced surface area for hazelnuts compared to other study contexts.

Table 2. Surface area (hectares) (top) and percentage (bottom) of hazelnuts for each municipality depending on DTM classes (meters).

	DTM classes (meters)					
	<250	250–500	500–750	750–1000	>1000	% Area Compared to Total
Castell'Umberto	0.0	10.7	85.5	12.9	0.0	2%
Montalbano Elicona	0.0	4.8	158.8	353.1	42.5	12%
Raccuja	0.0	0.5	143.1	195.0	18.3	8%
San Piero Patti	0.0	56.9	309.3	340.5	42.6	16%
San Salvatore di Fitalia	3.1	71.1	149.1	45.3	0.0	6%
Santa Domenica Vittoria	0.0	0.0	0.0	15.5	93.4	2%
Sant'Angelo di Brolo	0.8	70.5	346.9	191.8	0.0	13%
Sinagra	5.8	133.9	214.0	117.9	6.6	10%
Tortorici	0.0	31.9	313.1	368.4	58.2	17%
Ucria	0.0	24.9	173.0	317.6	43.3	12%
	<250 (%)	250–500 (%)	500–750 (%)	750–1000 (%)	>1000 (%)	Average DTM
Castell'Umberto	0%	10%	78%	12%	0%	627
Montalbano Elicona	0%	1%	28%	63%	8%	825
Raccuja	0%	0%	40%	55%	5%	802
San Piero Patti	0%	8%	41%	45%	6%	754
San Salvatore di Fitalia	1%	26%	56%	17%	0%	595
Santa Domenica Vittoria	0%	0%	0%	14%	86%	1088
Sant'Angelo di Brolo	0%	12%	57%	31%	0%	671
Sinagra	1%	28%	45%	25%	1%	614
Tortorici	0%	4%	41%	48%	8%	779
Ucria	0%	4%	31%	57%	8%	797
						755

Through the GIS program, maps concerning DTM, slope (classified in percentage terms), aspect, and curvature were produced (Figure 3). Starting from a DTM map the slope of the roads, which must be driven by the vehicles, and the specific slope of each hazelnut areas were calculated. Ambiguous contexts (such as a high degree of slope or altitude) have been assessed in a parallel analysis through available orthophoto investigation, even if the vegetation map detected hazelnut plants. Within this operation, the elevate degree of correctness of the vegetation map of Sicily can be confirmed.
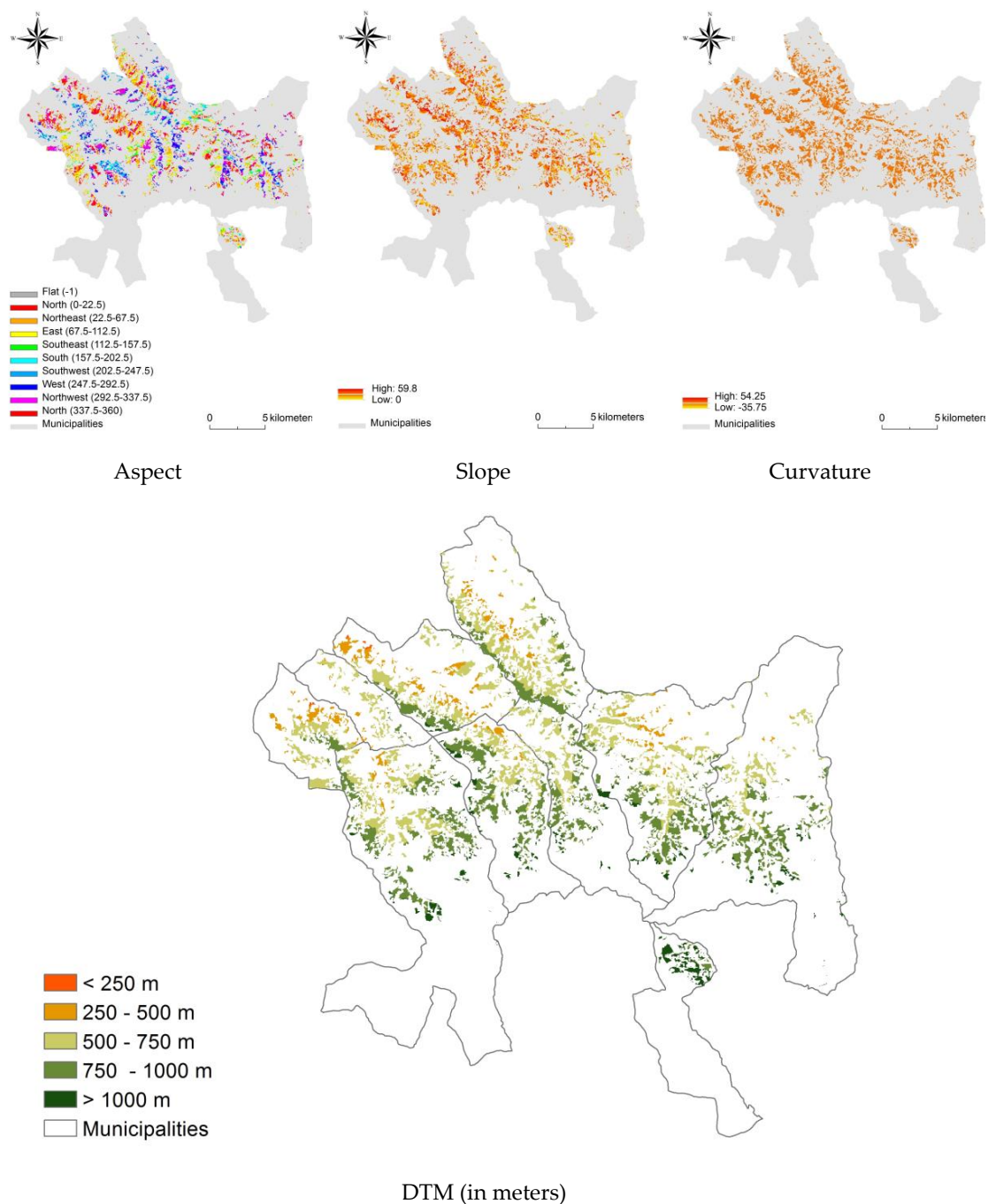
Aspect   Slope   Curvature

DTM (in meters)

Figure 3. Morphological structures of the territory using GIS program. Source: own elaboration.

The slope of hazelnut areas was classified into seven classes: '1': 0%; '2': 1–10%; '3': 11–20%; '4': 21–30%; '5': 31–40%; '6': 41–50%; '7': >50%. The slope of the streets in the ten municipalities was classified into 17 classes: '1': 0%; '2': 1–2%; '3': 3–4%; '4': 5–6%; '5': 7–8%; '6': 9–10%; '7': 11–12%; '8': 13–14%; '9': 15–16%; '10': 17–18%; '11': 19–20%; '12': 21–22%; '13': 23–24%; '14': 25–26%; '15': 27–28%; '16': 29–30%; '17': >30%. Zones with a steep slope (>30%) and high altitude (>1000 m) are the ones to avoid for mechanized harvesting as it results in increased risk for operators when they should collect hazelnuts.

Through the raster calculator tool using GIS program, the territory was analyzed observing the most suitable places to introduce mechanization processes. Figure 4 displays the optimal contexts for hazelnuts (in legend with the label "0"), with minimal risk for operators, where the slope is minimal,

with optimum altitudes to hazelnuts and ease in terms of mobility for the machines that need to reach such areas. There are also further favorable contexts for hazelnuts with good altitude and slopes. Finally, areas that should be avoided for greater risk for operators, due to their high altitude and slopes, discontinuous road system with strong slopes.
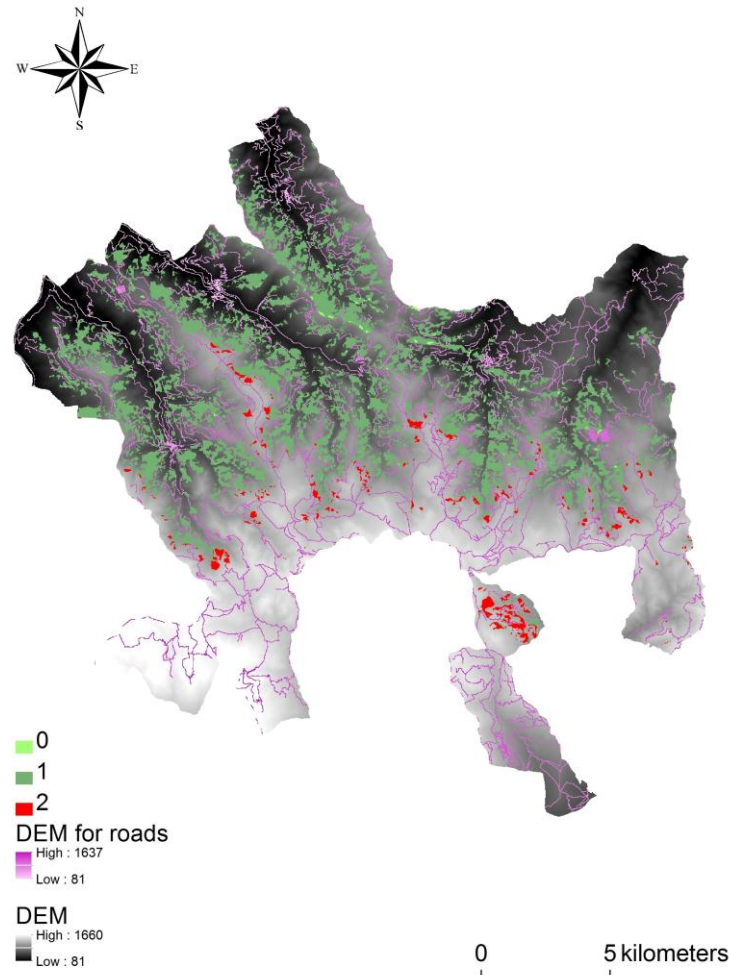

Figure 4. Possibility of mechanization. Legend 0: optimal areas for hazelnut, with minimal risk for operators; 1: favorable areas for hazelnut with good altitude and slopes. 2: areas to be avoided for greater risk for operators, including high altitude and slopes and road systems with strong slopes. Source: own elaboration.

Checking the results obtained, a region group elaboration was run using the GIS program. It identifies the degree of feasibility of cultivation and collection of hazelnuts depending on the morphological characteristics (Figure 5). Four groups of hazelnut areas can be observed. In this elaboration, the most optimal contexts emerge both to grow and manage the cultivation of hazelnuts and to provide the right security measures for the operators who must collect the hazelnuts (class "1"). In fact, in Figure 5, it is possible to clearly distinguish the southern zones, which are the ones that are higher in altitude (>1000 m), sloping (>30%) and mostly affect the safety of workers (class "4"). However, the best areas ("1") occupy only 430 hectares (about 9% compared to the total surface area of hazelnuts in the ten municipalities). Unsuitable contexts have a surface of 370 hectares (about 7% of the total surface area in analysis). The intermediate areas (classes "2" and "3" for the region group elaboration) are those that occupy the largest surface areas (almost 4200 hectares). Finally, 4600 hectares can be used as agro-energetic districts.
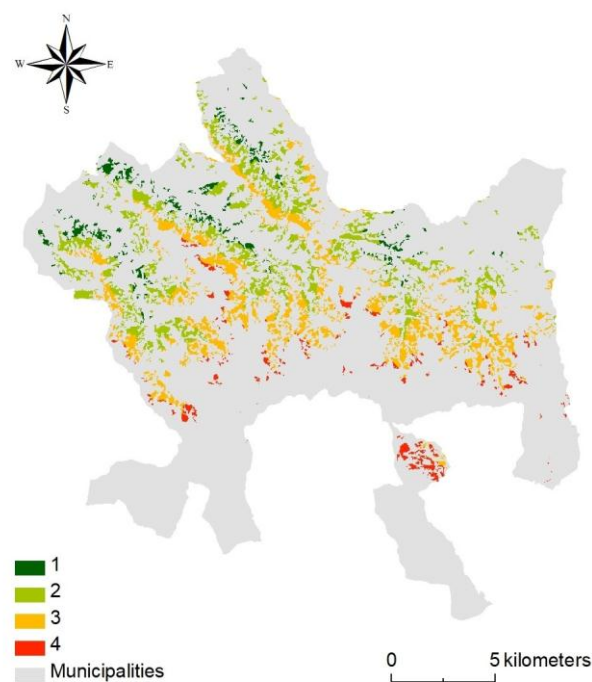
Figure 5. Region group elaboration using GIS program to identify the degree of feasibility of cultivation and collection of hazelnuts depending on the morphological and spatial characteristics. Source: own elaboration.

4. Discussion

Hazelnuts represents one of the major economic realities that constitute the primary sector of the Sicily region [49]. The latter is a unique Mediterranean context, given its climate, landscape, and peculiar characteristics [50,51]. Particularly, the Nebroidi park allows for the easy adaptability of hazelnuts [38]. However, high altitudes and the acclivity of slopes make it difficult to cultivate and harvest hazelnuts [42,43]. This study aims to identify the most favorable contexts to increase the growing and harvesting of hazelnuts using appropriate vehicles. First, the territorial characteristics should be considered, such as slope or the road system necessary to reach these contexts. Using and processing data through GIS technologies and databases obtained by remote sensing processes at local level was decisive.

Spatial data collection permitted the comparison of different databases. The vegetation map of Sicily has highlighted how a deep knowledge of the local contexts and the use of remote sensing and GIS technologies, in addition to a large bibliographic collection, allows for a detailed analysis, identifying several kinds of crops. In fact, limiting to a CLC map could causes an actual error in calculating surface areas destined for hazelnuts: only 63% of hazelnuts fall into the category of "orchards" in the CLC map. Data processing has confirmed the adequacy of the vegetation map of Sicily: most of the hazelnuts are found at slopes that are not too high (between 6% and 30%) [6] and at altitudes between 500 and 1000 m [41]. GIS processing has thus let to recognize the most appropriate areas for the hazelnuts, since their cultivation is not recommended on the steep slopes, since they cannot prevent and hinder environmental matters, as soil erosion processes [42,43]. Furthermore, when some contexts appeared uncertain (e.g., when the Vegetation map of Sicily detected hazelnut plantations along high degree of slope or altitude), a parallel analysis (orthophoto investigation of specific areas) assessed such outcomes, confirming the high correctness of the Vegetation map of Sicily.

Another issue that must be addressed in this paper concerns the collection of hazelnuts. In these contexts, traditional methods are still used, such as hand-picking. This makes the collection of hazelnuts expensive, wasteful, with high labor costs and long working hours. As a possible solution

to the mechanization of harvesting the nuts in soils with planting distances and irregular with steep slopes (from 24 to 35%), the prototype, proposed by [44] can adapt to the most difficult conditions. It is not necessary to use other harvester machines. Very often, hazelnuts are located along inclined slopes or unconnected areas, where traditional means of mechanization fail to work optimally. The prototype (i) is smaller than existing machines, (ii) ensures agility in maneuvering and high stability in steep slopes, (iii) is easy to use and versatile, (iv) reduces capital amortization times, (v) is easy to be transported by simple means such as small trolleys or pickups, (vi) increases the capacity to collect hazelnuts, and (vii) improves working conditions (e.g., substantial reduction in the risk of biomechanical overload compared to manual harvesting). The prototype of [44] allows for simple collection, safeguarding the health and safety of workers, and reduces the time necessary for the hazelnut harvest (e.g., it separates hazelnuts from other elements such as weeds or leaves). Furthermore, as a work accessory, the prototype proposed by [44] fits to other machines depending on the working context.

Besides identifying the most suitable areas, the present paper also aims to offer a chance of sustainable development, such as increasing cultivation of hazelnuts, protecting the workers' safety and optimizing work times concerning picking hazelnuts given the intrinsic territorial adversity. The concepts of circular economy and agro-energy districts could be effectively applied in these territories [52,53]. From the point of view of agro-energetic districts, it is assumed that the former depends on several parameters, i.e., the cultivation type and site and the planting distance, defining the most appropriate use of residual biomass [48]. For intensive farming of hazelnut, the pruned biomass can reach about 1848 kg/ha [54]. Obtainable residual biomass from hazelnut trees pruning can be positively considered as an actual economic chance for this area. From our study, it is possible to estimate to get a biomass of 8500 kg (4600 hectares).

In conclusion, from the economic point of view, a greater cultivation of hazelnuts would also give more employment alternatives, increasing the employment status and leading to a valorization of local agriculture [55]. As in other region (e.g., Latium and Piedmont in Italy or in Turkey) where hazelnuts are important for the primary sector [7,8,56–58], they can be defined as an economic resource in Sicily since they could provide income opportunities in hilly and mountainous areas where other agricultural activities are limited by the hostile environment [55]. Potential revenue deriving from this kind of cultivation can be estimated depending on how many hectares are put back into culture [55]. Finally, hazelnuts are defined as one of the most profitable fruit, demonstrating a high degree of sustainability, mostly owing to the low input necessities for orchard management and the opportunity of using agricultural waste as potential biomass [48,52,54,55,58,59].

5. Conclusions

The present paper started from the collection and comparison of available materials. The GIS elaboration is decisive for analyzing the Sicilian context and discriminate the spatial database by choosing the most appropriate one. Using this method, the most suitable area for cultivation hazelnuts can be detected. Also, innovative mechanization processes should be employed since they are still undeveloped and can mitigate the physical obstacles to hazelnut production (e.g., discontinuous road system, high slope). Finally, a sustainable vision is offered with the aim to promote a circular economy and agro-energetic district in this Sicilian context based on hazelnut cultivation.

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