Sodium Chronicles… grain by grain.
New methods for Quantifying Ancient Salt Demand.

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Supplemental Materials
Land Evaluation Values

As detailed in Sotgia (2024a), building upon and expanding the ideas proposed by Van Joolen (2003) and Goodchild (2007), it is possible to apply FAO's (1976) '*land evaluation'* techniques to archaeological contexts, adapting methods developed for the modern world to ancient settings.
To define these classes and considering the multi-faceted nature of agriculture, the factors to be analysed derive from both the physical and environmental realms, as well as from technological and socio-economic considerations. Therefore, the following factors are assessed to generate a model of the agro-pastoral suitability of the landscape.
All analytical operations were carried out in the ArcGIS Pro software environment (version 3.4.0, released in 2024) by ESRI, but they can be easily replicated using other Geographic Information Systems (GIS).

Environmental Factors

1. Slope

This factor influences agricultural activities in various ways. First and foremost, it is well known that as the slope of the land increases, both soil depth (partly due to erosion - *see below*) and fertility decrease. Additionally, steeper slopes require greater effort to cultivate, often necessitating the construction of terraces in more challenging cases.
Regarding the specific plants under consideration: Cereals and legumes grow best on flat or gently sloping land (Cato, *De Agricultura* 1.2-4; Columella, *De Re Rustica* 1.2.3-5). Olive trees and other fruit trees, by contrast, thrive on moderately sloped terrain (Columella, *De Re Rustica* 5.8.5), while flatter areas should be avoided due to the higher risk of waterlogging (Columella, *De Re Rustica* 5.8.6-7; Varro, *De Re Rustica* 1.6.6). A similar principle applies to vines, which are well-suited to hilly terrain or land with a slope sufficient to ensure good water drainage (Cato, *De Agricultura* 6.4; Columella, *De Re Rustica* 3.1.8-10; Virgil, *Georgics* 2.184-190; Varro, *De Re Rustica* 1.6.5, 1.9.5).

For the analysis of this factor, the slope values (expressed as a percentage – using the '*Slope*' tool of ArcGIS – Fig.1b) of the '*Digital Elevation Model*' (DEM with 10m resolution – Fig. 1a) from TINITALY (Tarquini, Nannipieri 2017 - https://tinitaly.pi.ingv.it/) were reclassified (Tool: *'Reclassify'*) according to the suitability values shown in Table 1 for each of the different species cultivated (Fig.2).

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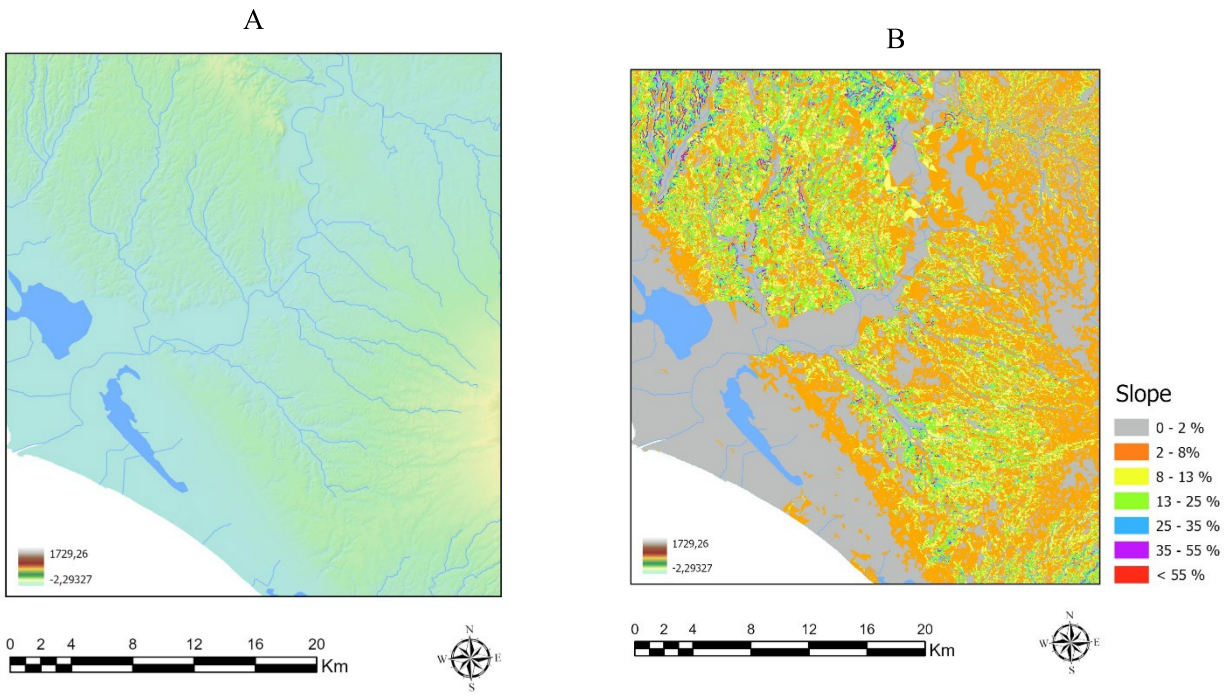

Fig. 1 – *Slope*
(A) Digital Elevation Model (DEM) at 10 m
(B) Slope of terrain expressed in %

<table>
<tr><th colspan="5">Slope</th></tr>
<tr><th></th><th>Wheat</th><th>Olive – Fruit</th><th>Grape</th><th>Legumes</th></tr>
<tr><td>0-2 %</td><td rowspan="2">10</td><td>1</td><td>1</td><td rowspan="2">10</td></tr>
<tr><td>2-8 %</td><td rowspan="3">10</td><td>10</td></tr>
<tr><td>8-13 %</td><td>7</td><td>9</td><td>7</td></tr>
<tr><td>13-25 %</td><td>5</td><td>8</td><td>5</td></tr>
<tr><td>25-35 %</td><td>2</td><td rowspan="2">6</td><td>7</td><td>2</td></tr>
<tr><td>35-55 %</td><td rowspan="2">1</td><td rowspan="2">1</td><td rowspan="2">1</td></tr>
<tr><td>> 55 %</td><td>1</td></tr>
</table>

Tab.1 – *Slope* – Suitability value for different plant species

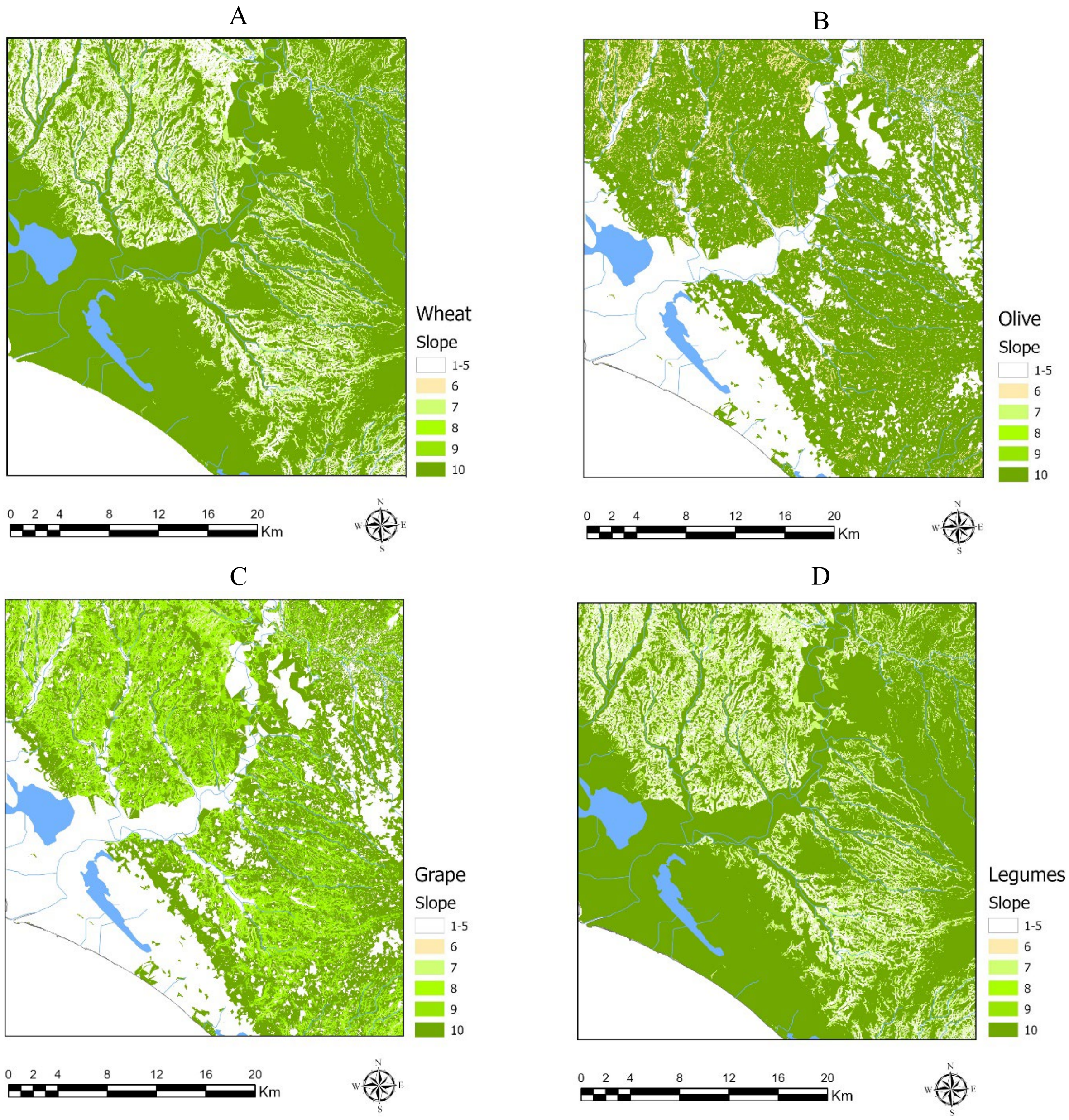

Fig. 2 – Agricultural suitability of land according with its slope
(A) Wheat; (B) Olive/Tree; (C) Grape; (D) Legumes.

2. Elevation

Depending on the elevation of a given plot of land, it will be subject to specific thermal conditions (temperature, oxygen availability, humidity, frost risk, etc.), which influence plant growth. For example, Akinci *et al.* (2013) estimate that in modern agriculture, there is a 4–6-day delay in the vegetative and flowering periods of plants for every 100-metre increase in altitude.
Roman agronomists, however, did not have a modern scientific understanding of altitude, and therefore do not explicitly discuss this factor. Nevertheless, indirect indications can be inferred by considering what they mention regarding the optimal temperatures for different crops.
Cereals, for instance, require stable, temperate climatic conditions (Cato, *De Agricultura* 10-12; Columella, *De Re Rustica* 1.3), which are most found in low- to mid-altitude regions. Likewise, olive treesthrive in warm, dry climates (Columella, *De Re Rustica* 5.1; Virgil, *Georgics* 2.20-40). Vines, on

the other hand, grow well at slightly higher altitudes though still relatively moderate (Columella, *De Re Rustica* 3.1.8-10; Varro, *De Re Rustica* 3.1.12).

For the analysis of this factor, the '*Digital Elevation Model*' (DEM with 10m resolution – Fig. 3a) from TINITALY (Tarquini, Nannipieri 2017 - https://tinitaly.pi.ingv.it/) was divided into twelve elevation classes (listed in Table 2 and shown in Fig. 3b), to which the following values were assigned (Tool: *'Reclassify'* – Fig.4):

<table>
<tr><th colspan="5">Elevation</th></tr>
<tr><th></th><th>Wheat</th><th>Olive – Fruit</th><th>Grape</th><th>Legumes</th></tr>
<tr><td>0 – 33 m</td><td rowspan="2">10</td><td rowspan="2">10</td><td>6</td><td rowspan="2">10</td></tr>
<tr><td>33 – 100 m</td><td>10</td></tr>
<tr><td>100 – 200 m</td><td>9</td><td>9</td><td>9</td><td>9</td></tr>
<tr><td>200 – 300 m</td><td>8</td><td>8</td><td>8</td><td>8</td></tr>
<tr><td>300 – 400 m</td><td>7</td><td>7</td><td>7</td><td>7</td></tr>
<tr><td>400 – 500 m</td><td>6</td><td rowspan="3">6</td><td rowspan="8">1</td><td>6</td></tr>
<tr><td>500 – 600 m</td><td>5</td><td>5</td></tr>
<tr><td>600 – 700 m</td><td>4</td><td>4</td></tr>
<tr><td>700 – 800 m</td><td>3</td><td rowspan="5">1</td><td>3</td></tr>
<tr><td>800 – 900 m</td><td>2</td><td>2</td></tr>
<tr><td>900 – 1000 m</td><td rowspan="2">1</td><td rowspan="2">1</td></tr>
<tr><td>> 1000 m</td></tr>
</table>

Tab.2 – *Elevation* – Suitability value for different plant species

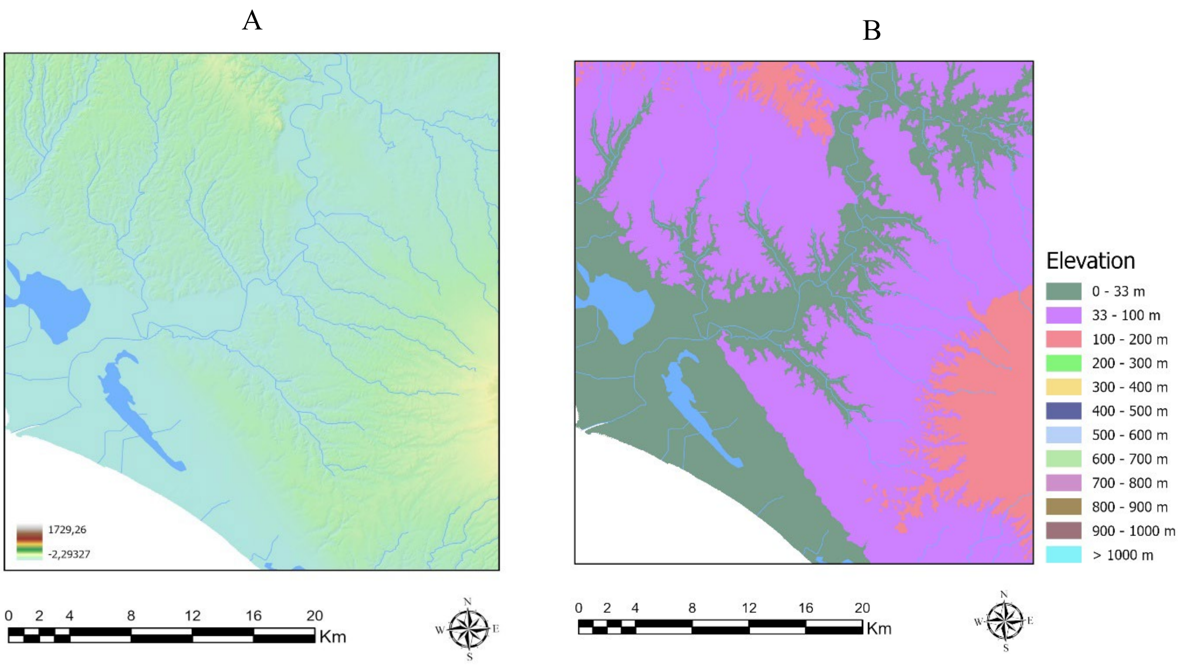

Fig. 3 – *Elevation*
(A) Digital Elevation Model (DEM) at 10 m
(B) Elevation Classes considered

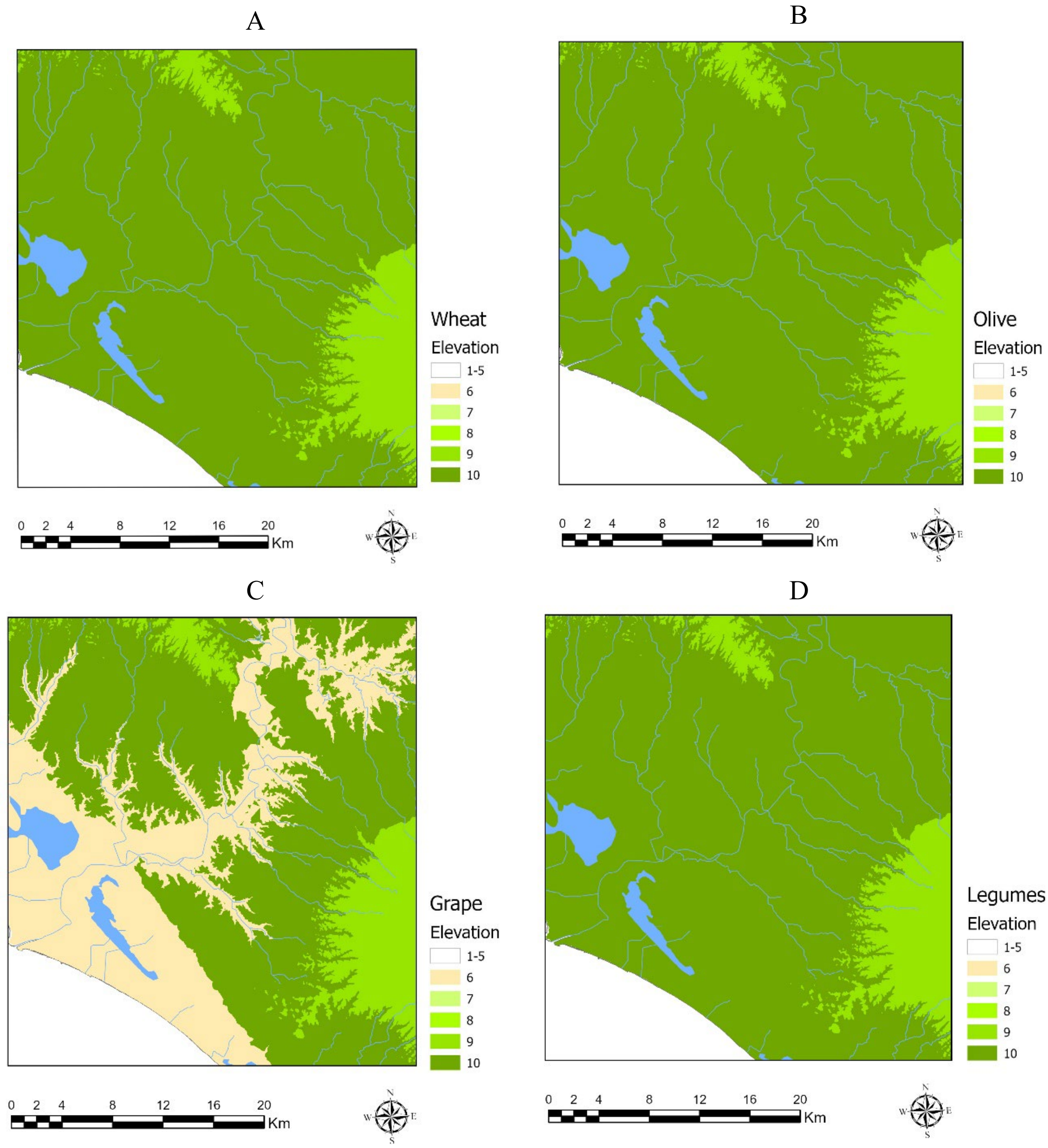

Fig. 4 – Agricultural suitability of land according with its Elevation
(A) Wheat; (B) Olive/Tree; (C) Grape; (D) Legumes.

3. Exposure

Exposure to sunlight is a critical factor for the photosynthesis process in plants and is also linked, like elevation, to variables such as temperature and humidity. Depending on the specific orientation of a plot, the land will receive varying amounts of sunlight throughout the day. While some plants benefit from extensive sunlight, excessive exposure can lead to water stress and soil dehydration in others.
The species considered here generally require a moderate to substantial amount of sunlight; however, the optimal orientation for sunlight exposure varies slightly. Cereals thrive in sunlit areas with eastern or southern exposure (Cato, *De Agricultura* 1.2-4, 34.2; Columella, *De Re Rustica* 2.9.3-5;). Olive trees, on the other hand, are better suited to land with a western orientation (Cato, *De Agricultura* 6.1-2, 40.2; Varro, *De Re Rustica* 1.24.1-2). Vines, meanwhile, favour a northern exposure (Cato, *De*

Agricultura 6.4), although they can also grow well in areas exposed to the southeast (Virgil, *Georgics* 2.184-190; Pliny the Elder, *Natural History* 17.19-22, 25, 29).

For the analysis of this factor, the '*Digital Elevation Model*' (DEM with 10m resolution – Fig. 5a) from TINITALY (Tarquini, Nannipieri 2017 - https://tinitaly.pi.ingv.it/) was was reclassified based on exposure, derived using the "*Aspect*" tool (Fig. 5b) in ArcGIS Pro. The different orientations were assigned the suitability values shown in Table 3 (Tool: *'Reclassify'* – Fig.6).

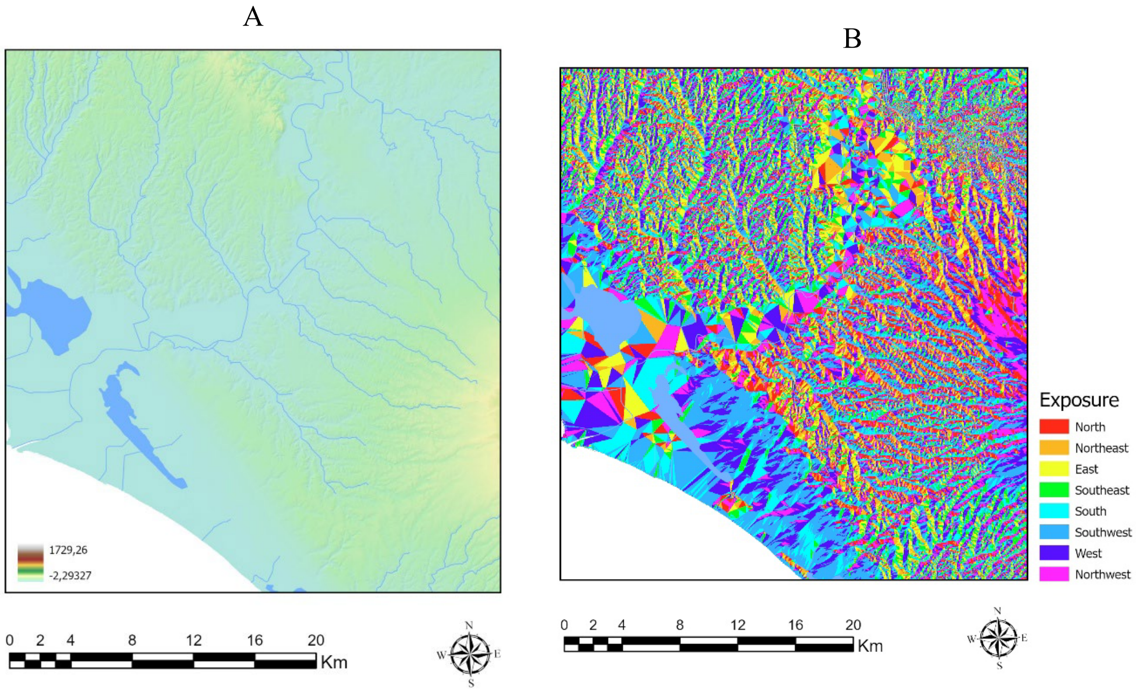

Fig. 5 – *Exposure*
(A) Digital Elevation Model (DEM) at 10 m
(B) Exposure of different terrains

<table>
<tr><th colspan="5">Exposure</th></tr>
<tr><td>Wheat</td><td>Wheat</td><td>Olive – Fruit</td><td>Grape</td><td>Legumes</td></tr>
<tr><td>North</td><td>1</td><td>6</td><td rowspan="2">10</td><td>1</td></tr>
<tr><td>North-East</td><td>6</td><td rowspan="3">1</td><td>6</td></tr>
<tr><td>East</td><td rowspan="3">10</td><td rowspan="3">6</td><td rowspan="3">10</td></tr>
<tr><td>Sud-East</td></tr>
<tr><td>Sud</td><td>6</td></tr>
<tr><td>Sud-West</td><td>6</td><td rowspan="3">10</td><td rowspan="3">1</td><td>6</td></tr>
<tr><td>West</td><td rowspan="2">1</td><td rowspan="2">1</td></tr>
<tr><td>North-West</td></tr>
</table>

Tab.3 – Exposure – Suitability value for different plant species

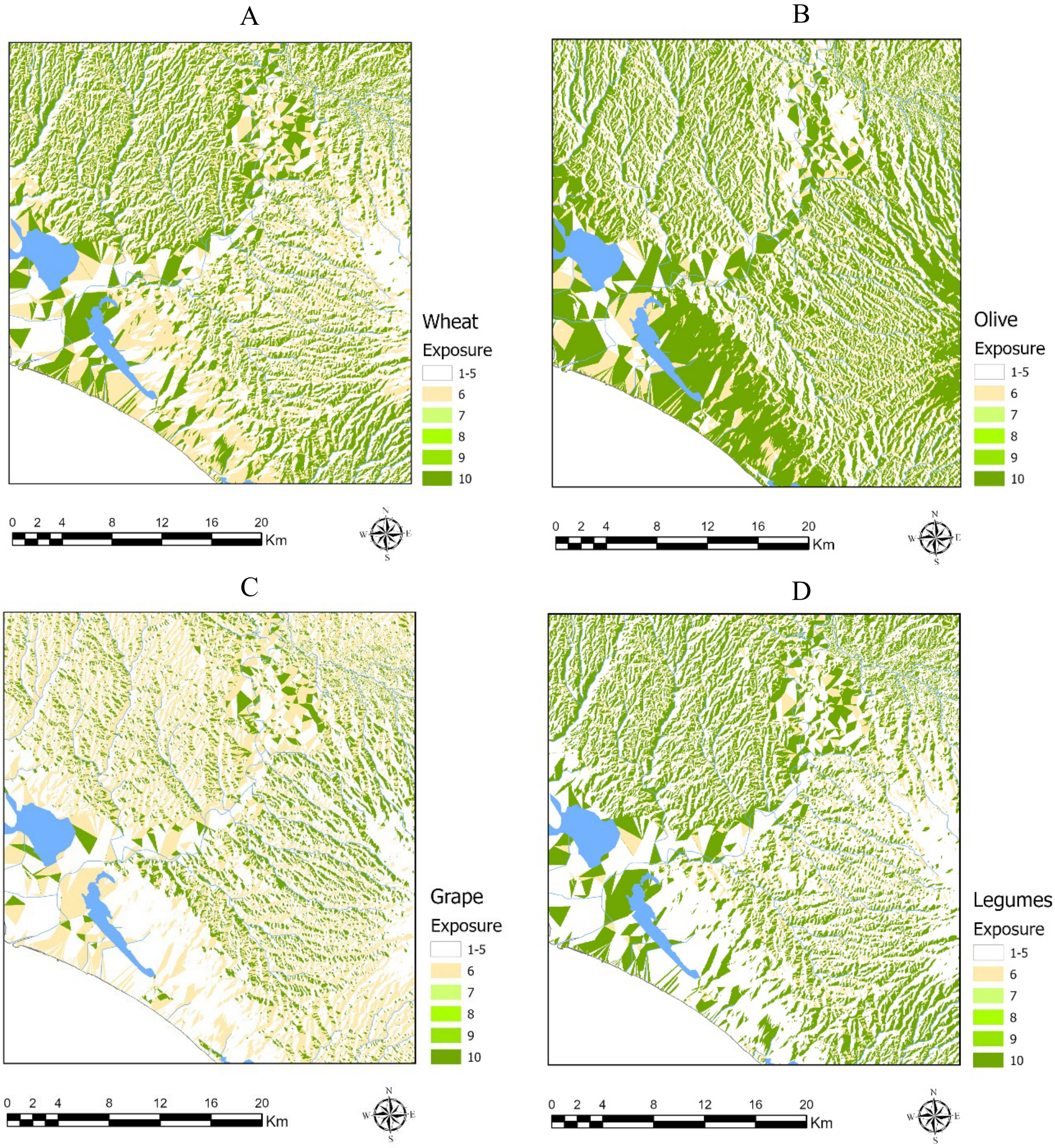

Fig. 6 – Agricultural suitability of land according with its Exposure
(A) Wheat; (B) Olive/Tree; (C) Grape; (D) Legumes.

4. Geology

The geological components (mineral composition and soil structure) of a plot determine its physical, chemical, and biological properties, such as nutrient availability, pH levels, and water retention capacity. These factors, in turn, influence plant growth and ultimately affect the fertility and productivity of a particular land in relation to the species cultivated there. Depending on the type of cereal intended for cultivation, either calcareous or clay soils may be more suitable (Cato, *De Agricultura* 6.1; Columella, *De Re Rustica* 2.9.3-5). Alternatively, alluvial or volcanic soils may also be preferred (Goodchild 2007; Sotgia 2024a). Olive trees thrive in soils comprising a mixture of gravel, gypsum, and coarse sand (Columella, *De Re Rustica* 5.8.5) or in fertile, moderately clayey soils that ensure good drainage (Virgil, *Georgics* 2.179-181). In the case of vines, sandy soils are ideal (Columella, *De Re Rustica* 3.1.8-10), and they are also preferred over moderately fertile soils (van

Joolen 2003). Finally, legumes, being robust plants, can adapt to a wide range of soil types, with a slight preference for clayey or clay-loam soils (Sotgia 2024a).
Moreover, the various geological components of a plot also influence its degree of 'workability.' For instance, the different types of ploughs affect the ease of tilling clay soils.
Therefore, the suitability rating pertaining to soil geology may vary depending on the chronological period under consideration.
To obtain this factor map, starting from the digitised version of the Soil Map of the area (Fig. 7 - Napoli *et al.* 2019), available on the Lazio Region Geoportal (https://geoportale.regione.lazio.it), suitability values (Table 4 – Fig. 8) were assigned (Tool: *'Reclassify')* to the different soil units according to their influence on the type of cultivation under consideration.

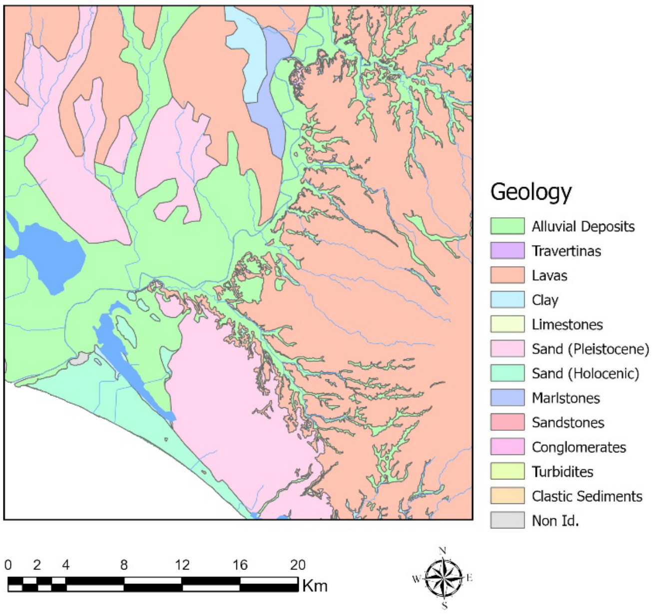

Fig. 7 – Soil Map (Lazio Region Geoportal)

	GEOLOGY				
		Wheat	*Olive – Fruit*	*Grape*	*Legumes*
1	Alluvial Deposits	10	5	7	8
2	Travertines	4	10	4	4
3	Lavas	10	6	10	8
4	Clay	8 (10)	8 (10)	8 (10)	10
5	Limestones	5	10	5	10
6	Sands (Pleistocene)	2	6	10	2
7	Sands (Holocenic)		2	2	
8	Marlstones	8	10	8	10
9	Sandstones	2	5	2	5
10	Conglomerates	5	5	5	5
11	Turbidites	5	8	5	5
12	Clastic Sediments	2	2	2	2
13	Non Id.	1	1	1	1
(Value) = Starting from the end of VIII BCE – introduction Iron Ploughs					

Tab.4 – Geology – Suitability value for different plant species

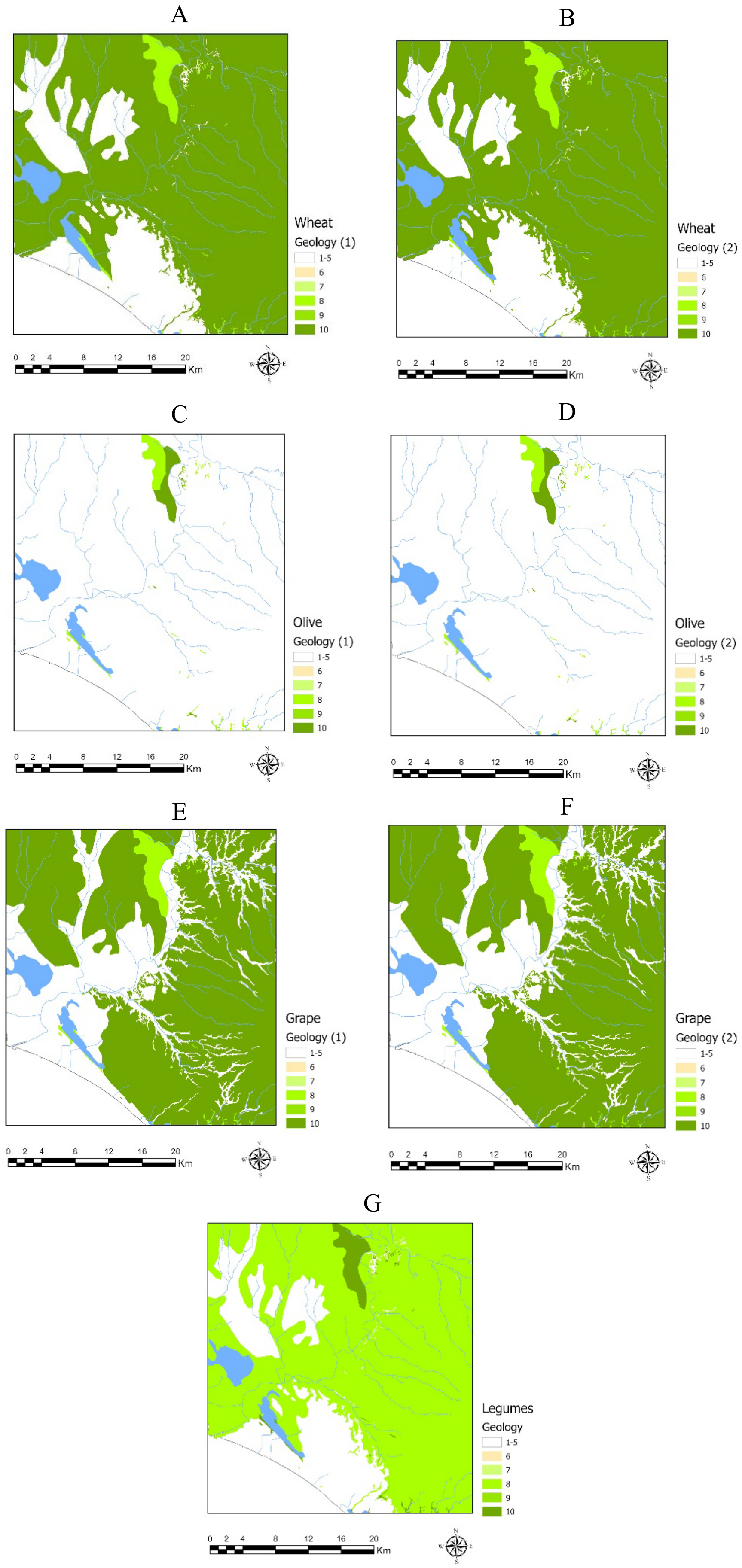

Fig. 8 – Agricultural suitability of land according with its Geology (A-B) Wheat; (C-D) Olive/Tree; (E-F) Grape; (G) Legumes.

5. Humidity index

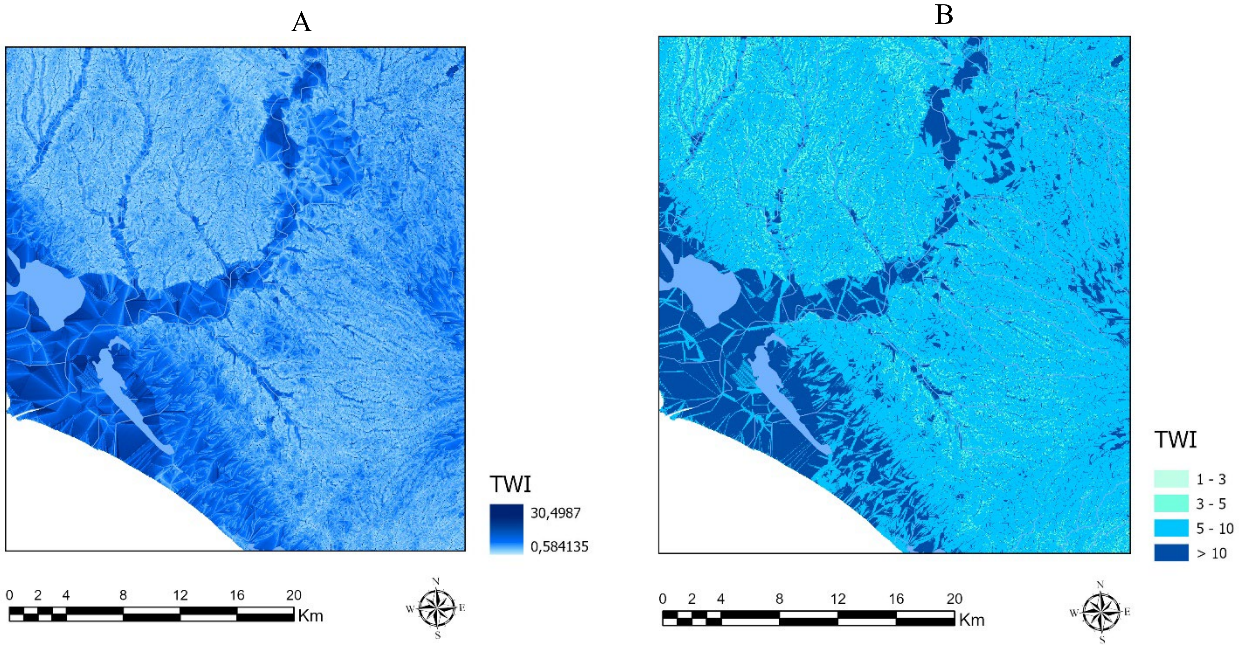

Fig. 9 – *Topographic Wetness Index*
(A) TWI
(B) TWI Classes considered

As discussed in many of the preceding factors, the drainage capacity of a plot and the consequent presence or absence of standing water play a significant role in the yield of a crop. Depending on the species in question, the specific degree of soil moisture will determine whether the plants can thrive. For cereals and olive trees, a dry but not arid soil is required (Cato, *De Agricultura* 6.1; Columella, *De Re Rustica* 1.2.3-5, 5.8.6-7), where the quantity of water does not result in excessive muddiness. Conversely, legumes and vines (Virgil, *Georgics* 2.184-190) thrive in decidedly wetter soils.
Consequently, a detailed analysis of this factor was conducted by calculating the Topographic Wetness Index for the entire area (Sorensen *et al.* 2006; Pei *et al.* 2010 – Fig. 9), and the following suitability values were assigned (Table 5 – Tool: "*Reclassify"* - Fig. 10).

TOPOGRAPHIC WETNESS INDEX – TWI				
	Wheat	*Olive – Fruit*	*Grape*	*Legumes*
1 – 3	10	10	1	1
3 – 5	8	8	7	10
5 – 10	7	7	10	7
> 10	1	1	1	1

Tab.4 – TWI – Suitability value for different plant species

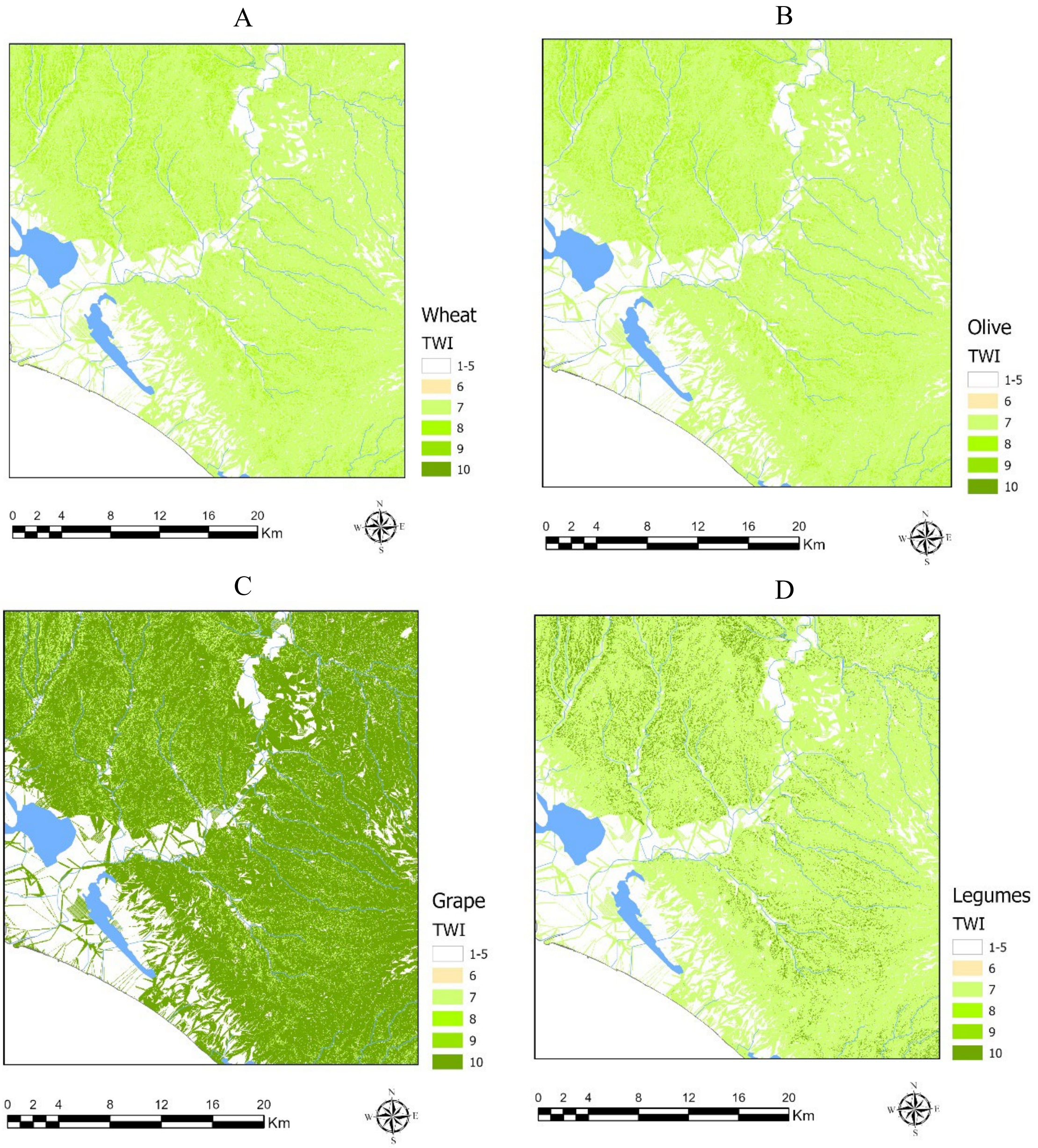

Fig. 10 – Agricultural suitability of land according with its TWI
(A-B) Wheat; (C-D) Olive/Tree; (E-F) Grape; (G) Legumes.

6. Proximity to water sources

Closely related to the availability of water for plants is the factor of distance between an area and its water sources, including lakes and rivers. Moreover, in terms of microclimate, the closer a plot is to a water source, the higher the humidity present in that area. As previously discussed, considering 1 km as the maximum distance within which a direct relationship exists, the suitability of a plot for cultivation in relation to water sources is as follows:

Distance from Water	
< 100 m	1
100 – 500 m	10
500 – 1000 m	6
> 1000 m	1

Tab.5 – Distance from Water: Suitability value

Within the GIS, this analysis was carried out by reclassifying (Tool: "*Reclassify"* - Fig. 11.c) a series of buffers (Tool: "*Multiple Buffer* - Fig.11.b) representing the specified distances around water bodies and rivers (Fig. 11.a). The latter were obtained through the application of the *'Hydrology'* tools in ArcGIS, as described in detail in Sotgia 2024a:16-20.

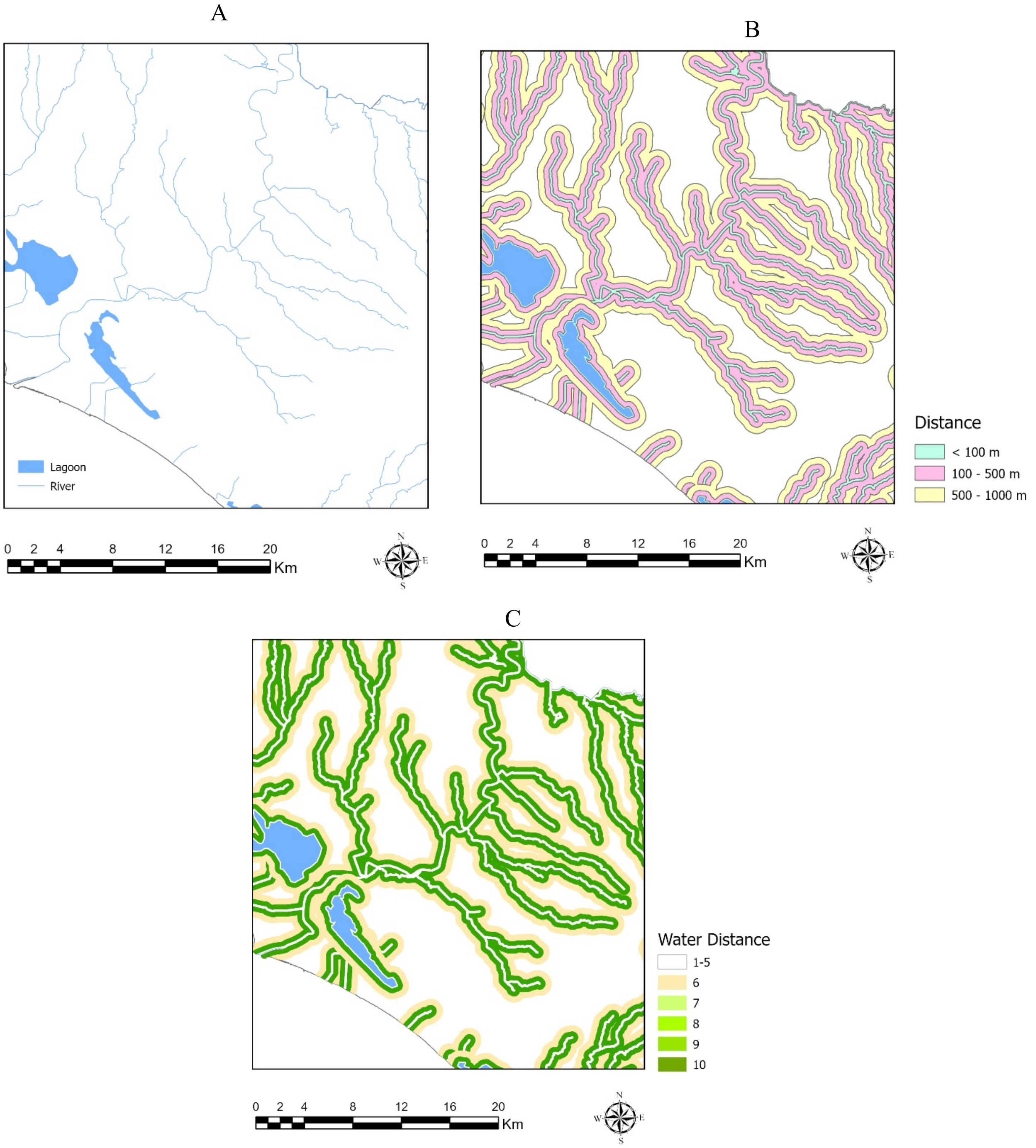

Fig. 11 – *Distance from Water*
(A) River and Lagoons;
(B) Distance Buffers;
(C) Agricultural suitability of land according with its distance from water

7. Erosion

The phenomenon of erosion significantly impacts agriculture by altering or removing varying quantities of soil. In extreme cases—since the process of erosion occurs more rapidly than sedimentation—this can lead to the exposure of bedrock, which is unsuitable for any form of cultivation. Various equations exist to calculate the effects of erosion, such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) or the Soil Erosion Index (SEI) developed by the FAO. These models take into account several variables, including the rainfall index for a specific area, slope percentage, terrain length, and the erodibility index, which considers soil texture, depth, and rockiness.
Additionally, when defining these equations, it is essential to consider conservation practices implemented to prevent erosion, such as the cultivation of specific plants whose roots help reduce soil loss. Regardless, as Davidson (1994) asserts, it is feasible to identify four risk classes for this phenomenon based on the slope percentage of a terrain and the corresponding percentage of eroded area.
To generate the factor map related to erosion, once the slope map (previously generated with the tool "*Slope*" – Fig.12.a) had been reclassified into four erosion classes (Fig.12.b), suitability values (Table 6) were assigned to these classes using the '*Reclassify'* tool (Fig.13).

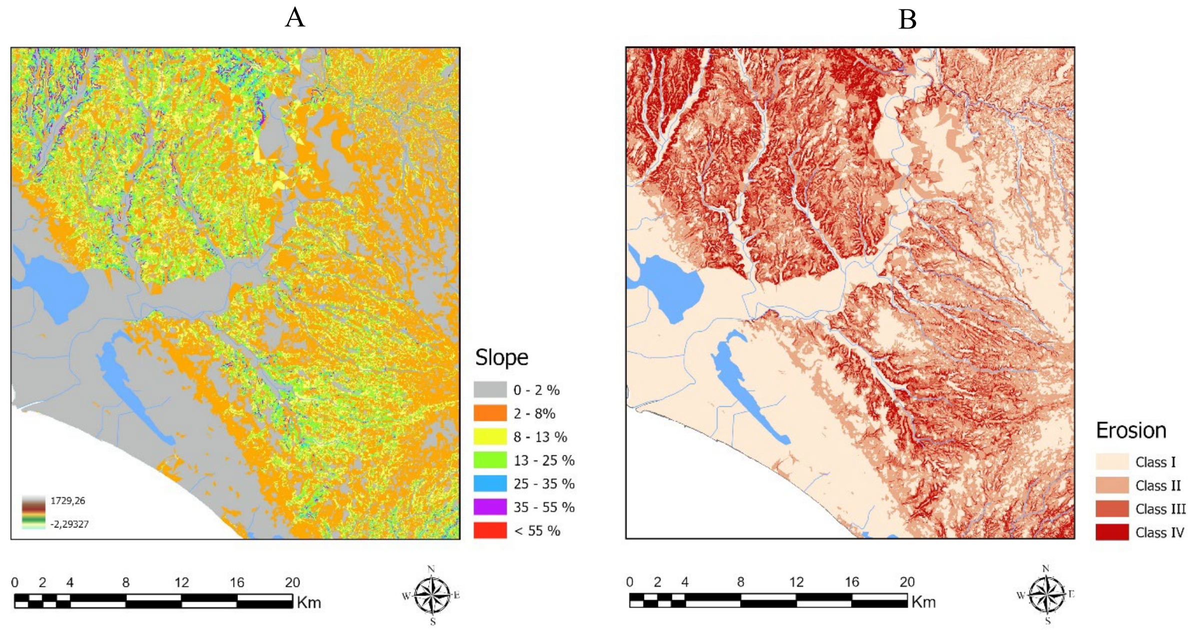

Fig. 12 – *Erosion*
(A) Slope of terrain expressed in %
(B) Erosion Classes considered

Erosion	
Class I Land with a slope of less than 3% where erosion does not occur.	10
Class II Land with a slope between 3% and 10% in which less than 30% of the original surface is eroded.	8
Class III Land with a slope between 10% and 18% in which more than 30% of the original surface is eroded.	6
Class IV Land with a slope greater than 18% in which the original surface is completely eroded.	4

Tab.6 – Erosion – Suitability value for different class considered

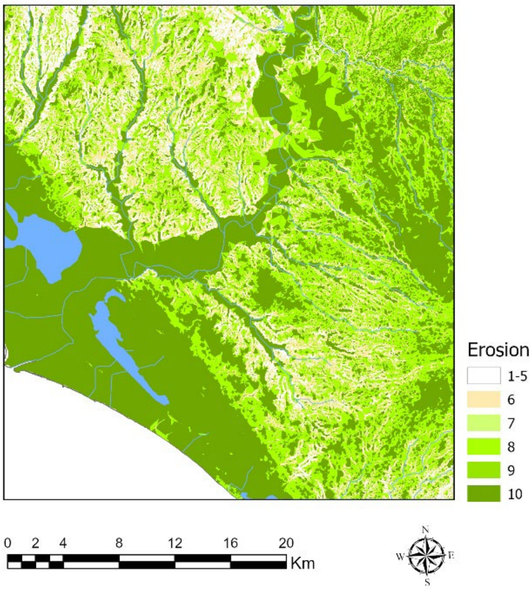

Fig. 13 – *Erosion:* Agricultural suitability of land

Social Factors:

8. Distance from Market locations

As discussed in Sotgia 2024b at a certain point, "primary" production began to exhibit more pronounced market-oriented characteristics both in terms of the quantity of plants cultivated and the specific type (i.e. increase in the production of wheat and olives compared to cereals from the 6th century BC onwards). Therefore, when defining the most suitable lands for agropastoral exploitation, it is essential to consider their distance from market locations.

Explicit references to this can be found in Columella (*De Re Rustica*, 1.2) and more broadly in the reflections on economic location, notably articulated in Van Thünen's model (1882).

In this context, "market locations" refer to primary and secondary settlements (Fig. 14.a) The suitability of lands in relation to their distance from these locations follows the schema presented in the subsequent table, employing a maximum distance of 5 km, as proposed by the Site Catchment Analysis (Higgs and Vita-Finzi 1975).

In GIS terms, this operation was performed through the creation of concentric buffers at different distances (Tool: *"Multiple Buffer"* - Fig. 14.b), which were subsequently reclassified according to the assigned suitability values (Table 7 – Tool: "*Reclassify" -* Fig. 14.c).

Distance from Market	
0 – 500 m	10
500 – 1 Km	9
1 – 1,5 Km	8
1,5 – 2 Km	7
2,5 Km	6
2,5 – 3 Km	5
3 – 3,5 Km	4
3,5 – 4 Km	3
4 – 4,5 Km	2
> 5 Km	1

Tab.7 – Distance from Markey: Suitability value

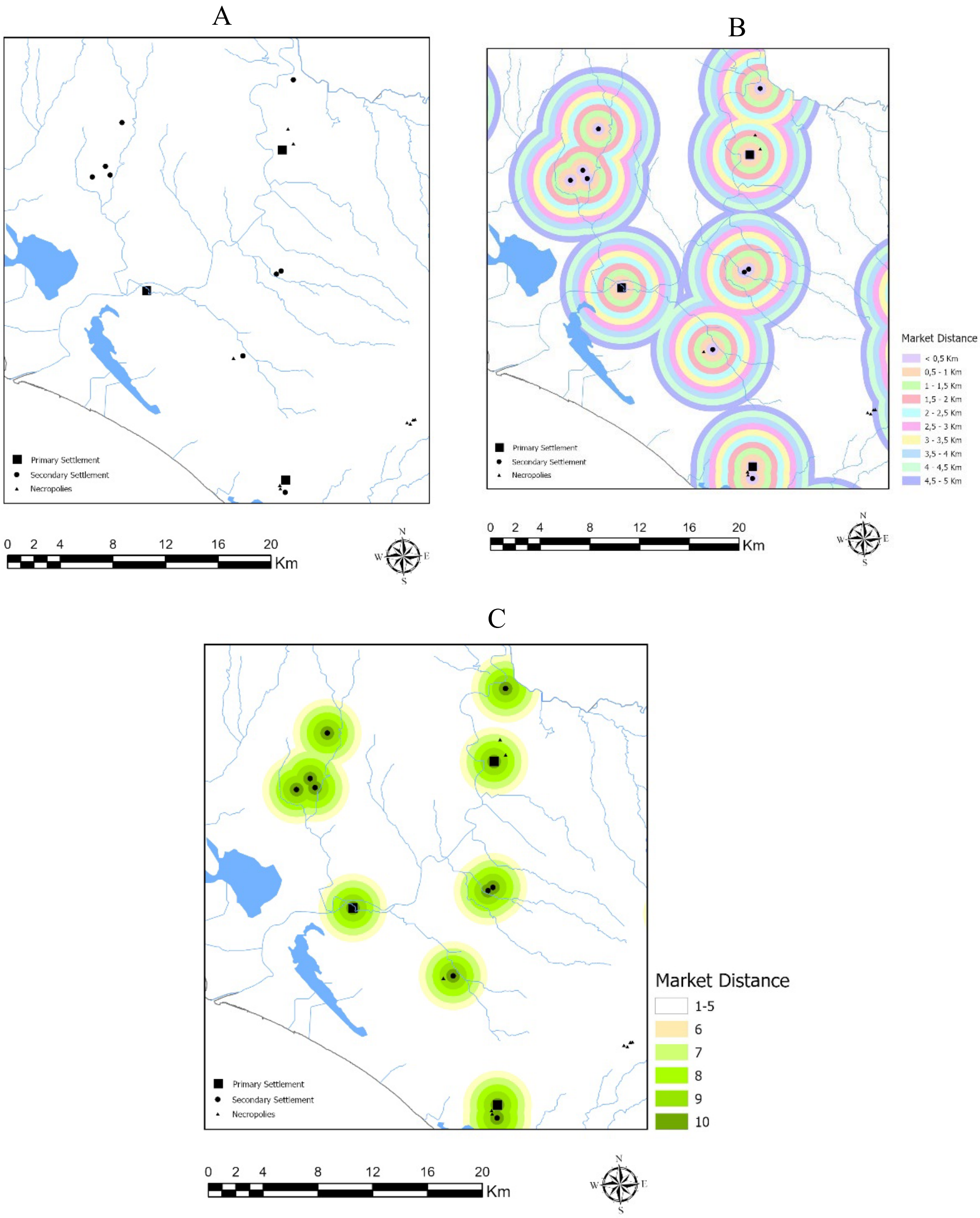

Fig. 14 – *Distance from Market*
(A) Sites
(B) Distance Buffers
(C) Agricultural suitability of land according with its distance from markets.

9. Proximity to Communication Routes

The distance of a given plot of land from primary communication routes is a factor intrinsically linked to economic and market considerations. For a thorough examination of the significance of studying Terrestrial Transportation Infrastructure (TTI) and an overview of the current state of research in the area under discussion, see the recent contribution by Prignano *et al.* (2019).
In the context of land evaluation, the factor of proximity to communication routes is modelled in a manner analogous to the assessment of proximity to water sources. This follows the views of Varro (*De Re Rustica* 1, 16, 6) and Columella (*De Re Rustica* 6,1), who stressed the importance of efficiently transporting goods from the place of production to the marketplace.

Similarly, as with the rivers, a series of buffers was created (Tool: “*Multiple Buffer* – Fig. 15.b*)* around the roads (Calculated with the tool: “*Least Coast Path”* – Fig. 15.a) and then reclassified according to the corresponding suitability values (Table 8 – Tool: “*Reclassify”* - Fig.15.c).

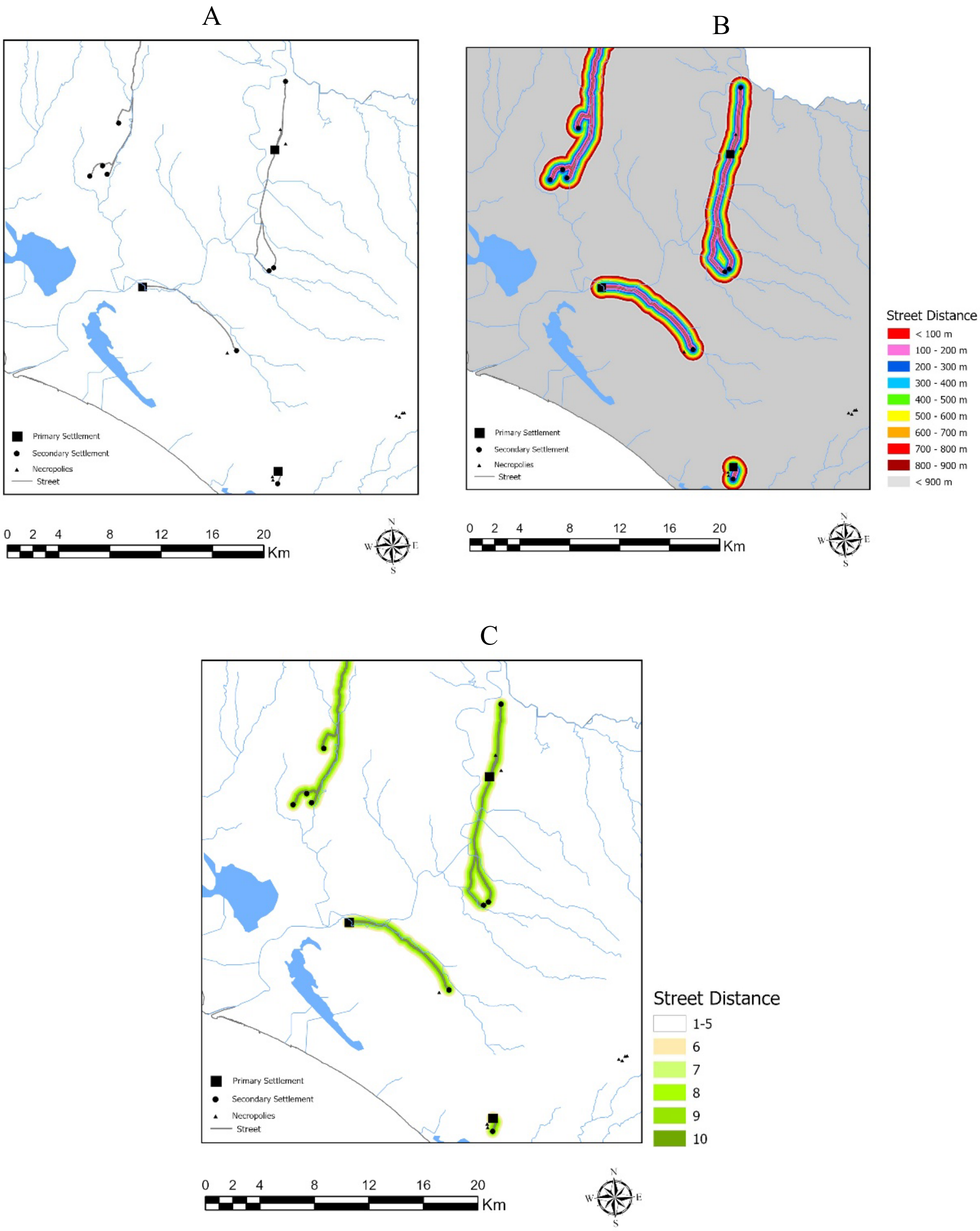

Fig. 15 – *Distance from Communication Routes*
(A) Street
(B) Distance Buffers
(C) Agricultural suitability of land according with its distance from communication routes.

Streets	
100 m	10
100 – 200 m	9
200 – 300 m	8
300 – 400 m	7
400 – 500 m	6
500 – 600 m	5
600 – 700 m	4
700 – 800 m	3
800 – 900 m	2
> 900 m	1

Tab.8 – Distance from communication routes: Suitability value

Definition of the overall model

Each of the factors considered held specific significance within the assessment of the suitability, or appropriateness, of a land for a particular purpose. For instance, it is well-documented that Latin agronomists placed greater emphasis on the workability of the soil, even prioritising it over its fertility (Sotgia 2024). Furthermore, the importance of a single factor could vary depending on the climatic conditions in question: during arid periods, factors related to water carried less weight, whereas in wetter periods, their significance increased.
The following table (Table 9) outlines the specific weight of each factor for different crops, depending on whether the period is characterised by a dry or humid climate, in accordance with the schema presented in Bernard *et al.* (2023).

	Cereals		Olive-Fruit		Grape		Legumes	
Factor	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*	*Wet*
Geology	30 %	20 %	25 %	20 %	25 %	20 %	30 %	30 %
Slope	20 %	20 %	25 %	25%	10 %	10 %	20 %	20 %
Altitude	10 %	10 %	10 %	10 %	15 %	10 %	5 %	5%
Exposure	10 %	10 %	10 %	5 %	15 %	15 %	10 %	10 %
Erosion	10 %	10 %	10 %	10 %	5 %	5 %	5 %	5 %
TWI	5 %	10 %	5 %	10 %	10 %	15 %	10 %	10 %
Water	5 %	10 %	5 %	10 %	10 %	15 %	10 %	10 %
“Market”	5 %	5 %	5 %	5 %	5 %	5 %	5 %	5 %
Routes	5 %	5 %	5 %	5 %	5 %	5 %	5 %	5 %

Tab.9 – Weight of each factor for different crops depending on climate situation.

By superimposing the various factor maps according to the weights previously (Tools: *“Weighted Overlay*”) delineated, one can derive the suitability models for each specific plant species under consideration (Fig. 16).
However, the practice of mixed agriculture during the period under examination necessitates an additional step to formulate a comprehensive model of agropastoral exploitation within the landscape. Consequently, the individual species models were amalgamated through a further overlay (Tools: *“Weighted Overlay*”), wherein the weight assigned to each plant corresponds to its percentage representation within the palaeobotanical record across the different chronological periods (Sotgia 2024b with specific references).

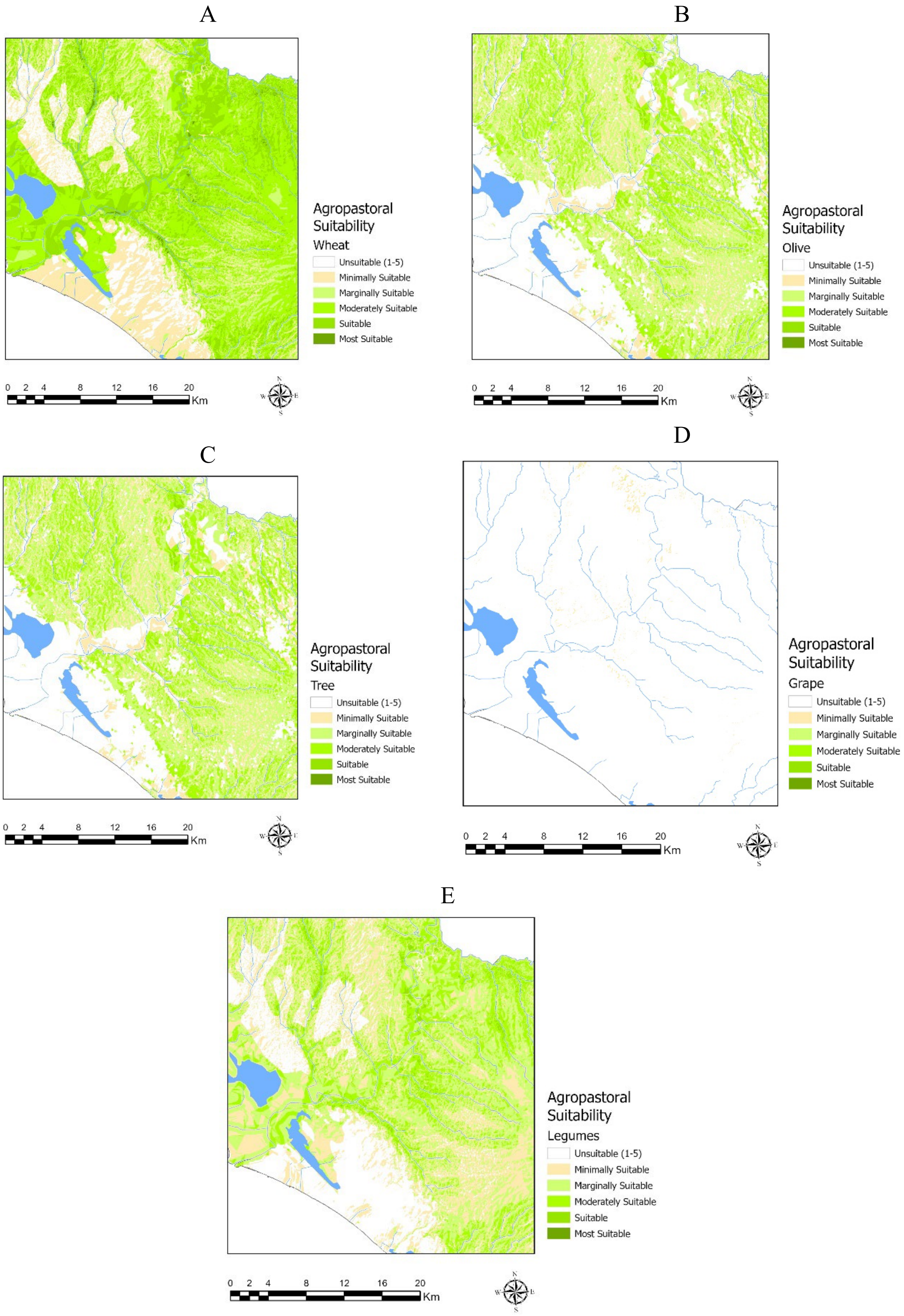

Fig. 16 – Agricultural suitability
(A) Wheat; (B) Olive; (C) Tree; (D) Grape; (E) Legumes.

For the present study, the following values (Table 10) were applied, resulting in the two agropastoral exploitation models illustrated in Figure 17.

	Climate	Wheat	Olive	Fruit Tree	Grape	Legumes
Period 1	Wet	70	5	2	3	20
Period 2	Wet	60	10	10	10	10

Tab. 10 – Climatic conditions and percentage of presence of the different cultivated species.

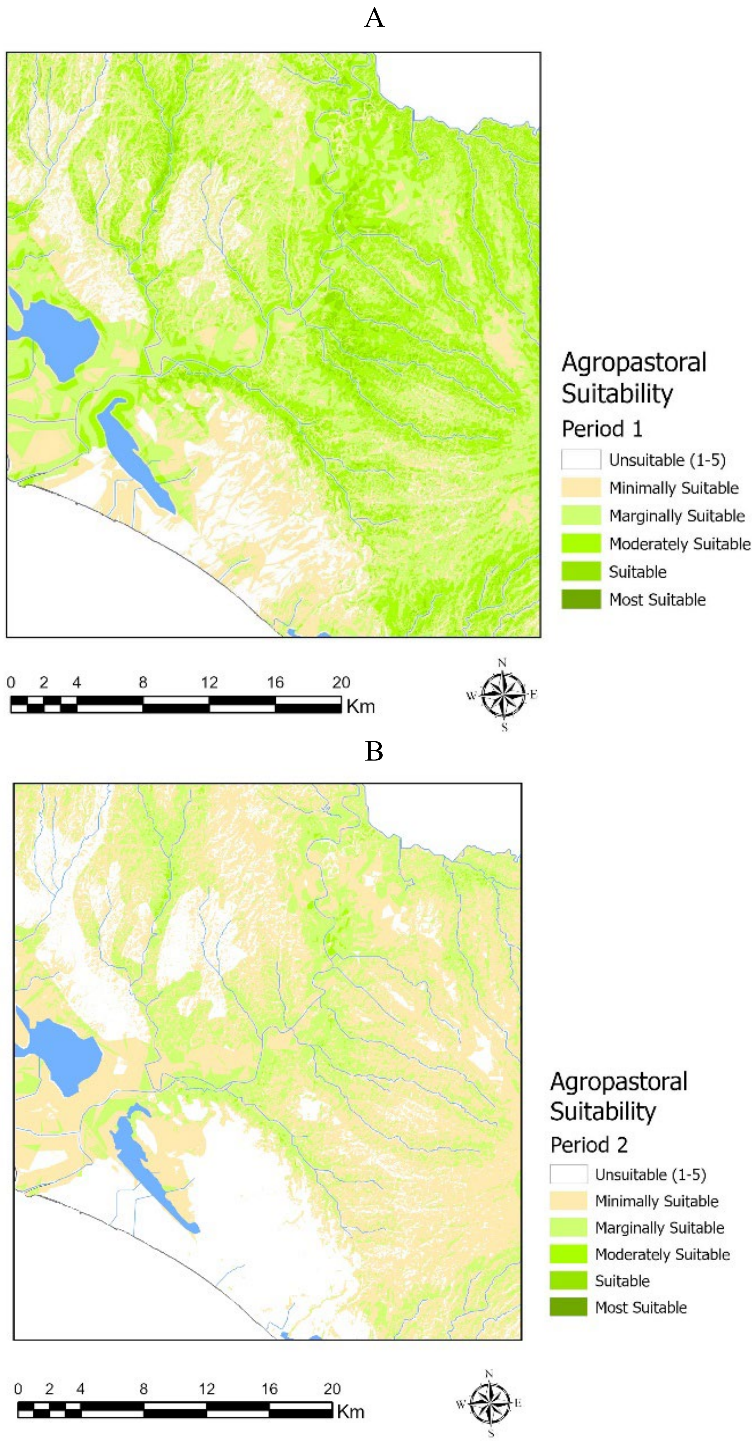

Fig. 17 – *Agropastoral Suitability Model of study area.*
(A) Period 1 - 750-650 BCE (B) Period 2 – 660-550 BCE

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