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Agricultural Land Suitability Analysis for Land Use Planning: The Case of the Madrid Region

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Abstract: Agricultural land is a key resource for territorial resilience. In the European context, fertile soils are under pressure not only from urbanisation processes, abandonment and the establishment of non-agricultural uses but also from agriculture that is not well adapted to territorial resources. In order to inform urban planning, a methodology is proposed and applied to the Madrid region to analyse the suitability of agricultural land uses with respect to agrological quality. The majority of agricultural uses in the region are well adapted to the agroecological quality of the land; larger areas of over-exploited land are located along some of the region's rivers and in the Campiña, while under-utilised land is mainly found in the south-west and in the metropolitan *comarcas*. This methodology is based on official and open-access information, so it can be easily replicated and used to inform land planning. We propose three strategies depending on the suitability of land use: the introduction of crops in priority areas for horticulture or arable crops, agricultural protection areas and ecological regeneration areas.

Keywords: agrological quality; land use; agricultural protection; land planning

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1. Introduction

Agricultural land is a strategic resource needed to increase food security and resilience in the context of global change. Land use change for agricultural land in Europe is an ongoing process. There was an approximate decrease of 136.660 km^2 in agricultural land between 1990 and 2006, with hotspots in Eastern European and Mediterranean countries [1].

Several factors lead to agricultural land use changes. Four main land and farming system dynamics take place in the Mediterranean Basin: intensification, extensification, abandonment and urbanisation [2]. Residential, industrial and recreational developments are mostly located on high- and medium-quality soils suitable for agriculture [3]. Urban pressure leads to the abandonment and disappearance of productive agricultural land [4], mainly in periurban areas, where there is a mutual influence between planning and agricultural land loss [5].

But even in rural areas, competing land use demands lead to conflicts. 'Urbanisation, food production, renewable energy production, environmental protection, and climate protection are known as key land use interests in many regions' [6]. The establishment of large-scale photovoltaic plants on agricultural land has been described by some authors as invisible land-grabbing, highlighting the conflicts over land use planning [7]. Throughout Europe, land use planning decisions leading to the transition to renewable energy must find a way to avoid impacts on high-value natural and agricultural areas [8].

Furthermore, the abandonment of agricultural land is one of the major land use change processes in Europe [9], particularly affecting remote rural areas, mountain regions and semiarid environments [10]. The highest risk of abandonment in Europe is found in the Mediterranean, Scandinavian and Baltic countries [11]. There are different approaches to tackling farmland abandonment. Some authors point out that the cultural and ecological values of traditional landscapes need to be preserved, taking into account the role these areas play in providing ecosystem services and conserving biodiversity [12]. Others suggest that rewilding and natural plant succession may be the better option for some areas [13].

Even if agricultural activity is maintained, it may not be adequate if it depletes available soil and water resources. Crops need to be adapted to the productive capacity of agricultural land so as not to degrade it. Intensive farming systems, disconnected from the reproductive cycles of the territory, cause the degradation and depletion of soil and water resources, leading to a loss of soil productivity [14], as well as a reduction in biodiversity and the fragmentation of ecosystems. Europe has some of the most intensive agricultural systems in the world [15]. Almost 70% of soils in the EU are in an unhealthy condition, being agricultural land pressured by erosion, land take, carbon loss, eutrophication, compaction and salinisation [16].

Many studies have been carried out on agricultural land suitability analysis, based on crop requirements and land characteristics, using a multi-criterion evaluation [17,18]. Land suitability analysis is intended to inform authorities, decision makers and farmers in order to better allocate land use, reduce land degradation and promote efficient management systems in agricultural policies and land use planning [19–22]. Fewer studies have compared soil quality with current crop cultivation [23–26] to determine how effectively land is being used for agriculture, to identify land with potential for the cultivation of more suitable crops and to ‘identify gaps and opportunities for optimising land use, improving agricultural productivity, and ensuring sustainable land management practices’ [23]. This is the objective of the proposed methodology, which is applied to the Madrid region to map the level of suitability of agricultural uses. The ultimate aim is to provide insights that inform land use planning, thereby facilitating the enhanced consideration of agricultural land. This would lead to greater regional sustainability, to the adaptation of agricultural uses to territorial resources and to the regeneration of urban–rural links by enhancing the capacity of food provision from a bioregional perspective [27].

Specifically, in the case study analysed, the functional region of Madrid extends beyond its administrative boundaries, and its rapid growth reflects a lack of coordination with neighbouring regions despite shared environmental, demographic and urban pressures [28,29]. Urbanisation, largely driven by economic liberalisation and municipal competition for investment, has led to significant land transformation [30]. Between 1990 and 2018, agricultural land in the Community of Madrid underwent a significant transformation due to urban expansion, doubling its artificial surface from 60,000 to 120,000 hectares and covering 15% of the region [31]. Urbanisation followed major transport corridors, expanding continuously along highways, while land use increasingly shifted towards industrial and commercial purposes. This expansion has fragmented the region’s agricultural landscape and contributed to a spatial mosaic of disorderly urban sprawl [32]. Agricultural areas have no specific protection under Regional Law 9/2001 on the Land of the Community of Madrid. Protection is only addressed by Law 7/2021 on Climate Change and Energy Transition, which refers to the conservation of land for ecosystemic reasons and may provide an alternative framework for this issue. Several authors argue that urban expansion must be regulated by municipal and regional policies to protect areas of high agricultural and natural value, preventing their transformation into urban or industrial areas [33,34]. Both urban and regional planning are important in achieving these goals. At the municipal level, urban planning regulates land use within its administrative boundaries and should protect valuable agricultural land, while territorial and sectoral planning must ensure coordination between different municipalities and address challenges that transcend local boundaries. In recent decades, Spanish land planning has paid increasing attention to agricultural land, recognising the supply, cultural and environmental functions that these soils can fulfil. This shift is evident in urban plans of various scales, as well as in sectoral plans, such as those focused on green infrastructure or landscape protection [35–37]. In the Madrid region, the concept of agricultural parks emerges as a valuable element of protection [38], though a lot of land is still unprotected [39].

2. Materials and Methods

Considering that the objective of this work is to evaluate the suitability of agricultural uses in the given territory, the methodology constructed addresses in a differentiated manner the processing of two databases. On the one hand, it is necessary to characterise agricultural uses to analyse the distribution of crops in the territory. On the other hand, we must study the capacity of the soils themselves to accommodate these agricultural uses. The intersection of these aspects allows us to assess the suitability of each agricultural use for the territory that supports it [40]. This double processing for the subsequent intersection is shown in the methodological scheme in Figure 1.

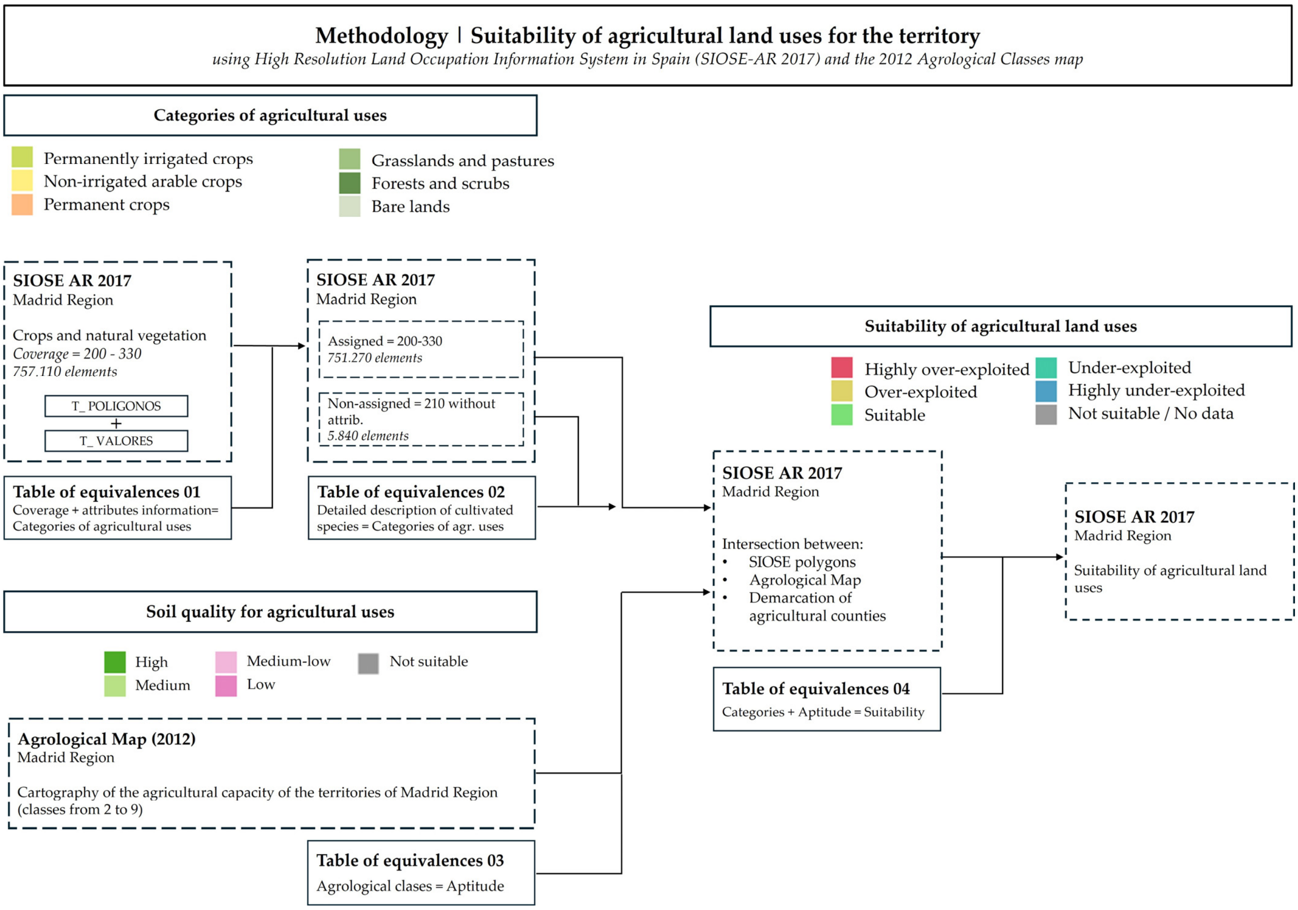


Figure 1. Methodology: suitability of agricultural uses for the territory based on the categorisation of agricultural uses and soil suitability. Data sources and processing.

The categorisation of agricultural uses sets as its main data source one of the land occupation mapping systems available in Spain: the High Resolution Land Occupation

Information System (SIOSE-AR 2017). The SIOSE-AR database is built from the integration of highly detailed geospatial sources.

SIOSE polygons have associated information on land use, including its percentage of occupation and a series of attributes depending on its type. The coverages describe the land use, adapted to the Hierarchical INSPIRE Land Use Classification System (HILUCS). Each polygon is assigned a numerical identifier representing the most significant cover type, ranging from 101 to 145 for artificial areas, 200 to 290 for crops, 300 to 354 for natural areas, 400 to 423 for wetlands and 500 to 523 for water areas. Our objective was to analyse agricultural uses and natural vegetation areas, so we started by selecting all the polygons with a coverage code between 200 and 330, excluding urban areas, buildings, artificial soils, infrastructure and water bodies. This selection contained 757,110 polygons covering 80.30% of the surface area of Madrid region.

In order to analyse territorial dynamics, the territory was divided using the demarcation of six agricultural *comarcas*, or counties, which group Spanish municipalities into districts with similar agricultural uses and territorial characteristics [41]. The metropolitan area is a region of gentle topography; it is a transitional zone between the Sierra de Guadarrama and the fertile lowlands of Jarama. The geological substrate consists mainly of conglomerates, arkosic sands, clays, limestone and gypsum. Soils have a slightly neutral pH, little organic matter and a sandy clay–loam texture.

The *Comarca* Campiña is an area of large fluvial terraces with gently undulating terrain and fertile soils washed by the rivers Jarama and Henares (one municipality also by the Tajuña). Xerochrept soils cover 73% of the area. They are deep (100–150 cm) and have a low organic matter content, a slightly acid pH and a sandy loam texture.

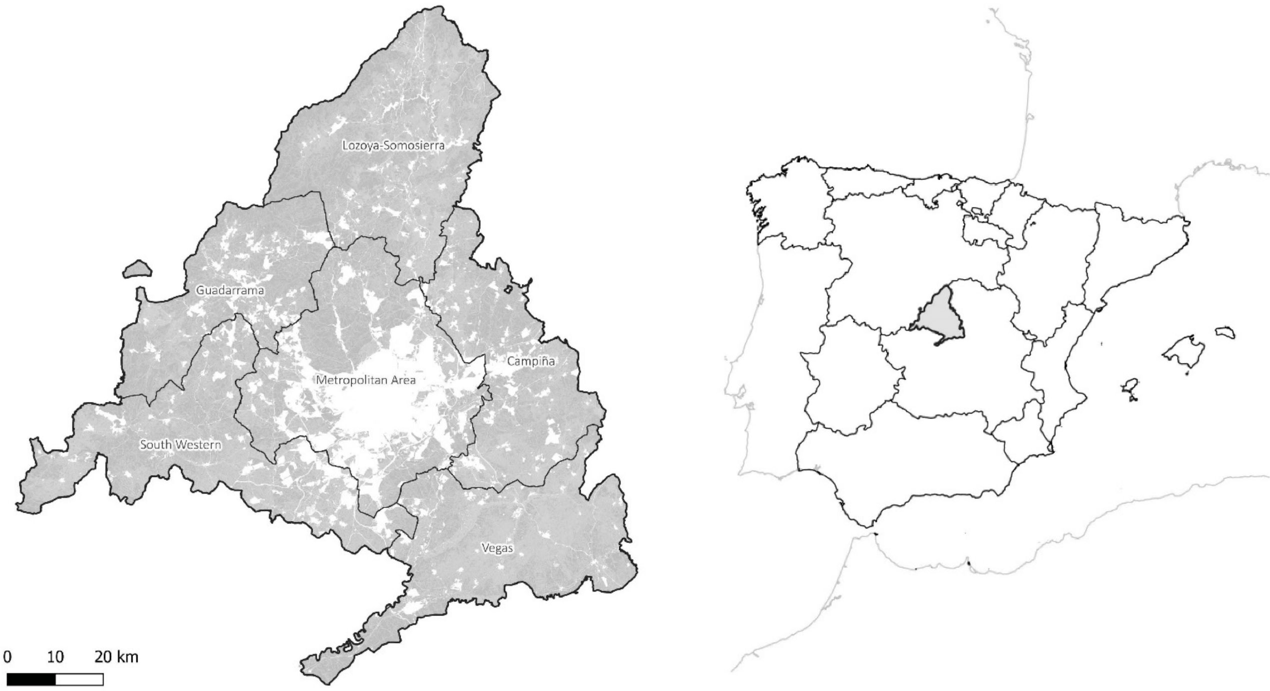
Comarca Guadarrama is a mountainous area with a rugged relief, containing the River Guadarrama and four reservoirs. It is the water catchment area of urban zones. The dominant geological substratum is made up of granite. Xerochrept soils predominate (71%); they are deep soils (100–150 cm). They have low organic matter content, a slightly acid pH and a sandy loam texture. In the sierra, the cold or frost period (number of months in which the average minimum temperature is below 7 °C) lasts eight months. The Sierra de Guadarrama Natural Park is characterised by its rich vegetation.

Comarca Lozoya-Somosierra is mainly a mountainous topography, crossed by rivers with many reservoirs. It is the main water catchment area for the metropolitan settlements. There is a high presence of shale, gneiss and granite, as well as sandstone, clay, conglomerate, marl, limestone and gypsum. In addition to xerochrept soils (56% of the area), there are other soils rich in organic matter, xerumbrept (25%) and cryumbrept (17%).

The Southwestern *Comarca* has a gentle topography, with some mountainous presence in its westernmost area but with a predominance of the plateau. The rivers that cross it are the Alberche and the Guadarrama, and there are three reservoirs.

Comarca Las Vegas is a zone of gentle topography, mainly characterised by the moors and meadows of the four rivers that flow through it. Xerochrept soils predominate, with a sandy loam texture and little organic matter.

Figure 2 shows the distribution of agricultural and natural areas in the six agricultural counties of the Madrid region. While the metropolitan area of Madrid has 54% of its land dedicated to agricultural uses and natural vegetation, *comarcas* such as Lozoya-Somosierra and Vegas have more than 90%, showing the different configurations of Madrid's territory.



Agricultural counties	Metropolitan Area	Campiña	Guadarrama	Lozoya-Somosierra	South Western	Vegas	Madrid Region
Crops and natural vegetation	94,208	91,557	83,000	139,553	116,952	118,916	644,185
Total area	173,774	107,931	97,166	153,251	139,416	130,701	802,239
Percentage	54.21%	84.83%	85.42%	91.06%	83.89%	90.98%	80.30%

Figure 2. Location of the case study: agricultural land in the Madrid region. Delimitation of agricultural counties and surfaces designated for crops and natural vegetation (hectares, ha).

In order to categorise the multitude of agricultural uses, seven categories were selected. These groups have different soil and water requirements, which allow us to differentiate the suitability of land uses:

- Permanently irrigated crops;
- Non-irrigated arable crops;
- Permanent crops;
- Grasslands and pastures;
- Forests and scrubs;
- Bare lands.

For this purpose, the original database went through a double process. First, we combined the information of coverage and attributes (ID_COBERTURA and ID_ATRIBUTO) in order to assign categories for agricultural uses. The coverage field contains the most basic information of the land use, such as the type of crops or vegetation it contains (fruit orchards, olive groves, vineyards, pastures, coniferous forests, etc.), while the attribute provides the specific characteristics of the agricultural uses (level of irrigation, use of greenhouses, etc.). Joining these two fields and assigning categories to each combination allowed us to build the first table of equivalences (01). These four tables are available in the Supplementary Materials section at the end of the article.

However, we found some difficulties assigning a category to the arable crops (ID = 210) that did not have attribute information due to their ambiguity. There were 5840 polygons in this condition, so we used another data field available from SIOSE. The label (ROTULO field) has specific information for the combination of plant species contained in each polygon. This allowed us to make a detailed assignment of categories based on the plant species (table of equivalences 02), completing this categorisation of agricultural uses.

The second process was related to the soil's quality for agricultural uses, based on the Agrological Map of the Madrid Region. This cartography divides the territory agrological classes, considering soil limitations for crops: climate, erosion, excess water in the soil, root zone conditions, tilling techniques and, in the case of irrigated land, the quality of irrigation water [42]. There are eight agrological classes, with 1 being the most favourable class for agricultural uses and 8 the least favourable. The Agrological Map's methodology includes recommendations for possible uses in order to maximise land use profitability.

The procedure used to incorporate this information to the shapefile layer was spatial intersection in GIS, assigning the corresponding class to each polygon according to the Agrological Map. Furthermore, the eight agrological classes were grouped into four levels of suitability for agricultural uses: high (class 2, since class 1 does not exist in the Madrid region), medium (class 3), medium–low (class 4) and low (classes 5–7). Class 8 was directly assigned as not suitable for agricultural uses.

As a result, the final database was a shapefile layer with information on agricultural uses and soil quality. The intersection of both characteristics allowed us to evaluate the suitability of the crops for the territory that hosts them, as detailed in Figure 3. This intersection classified each plot into four levels of suitability, going from high under-exploitation to high over-exploitation, following the methodology developed by Simon-Rojo [43].

Suitability of agricultural land uses		Categories of agricultural uses					
		Permanently irrigated crops	**Non-irrigated arable crops**	**Permanent crops**	**Grasslands and pastures**	**Forests and scrubs**	**Bare lands**
Aptitude for agricultural uses	**High**	Suitable	Under-exploited	Under-exploited	Under-exploited	Highly under-exploited	Highly under-exploited
	Medium	Over-exploited	Suitable	Suitable	Under-exploited	Under-exploited	Highly under-exploited
	Medium–low	Highly over-exploited	Over-exploited	Suitable	Suitable	Suitable	Under-exploited
	Low	Highly over-exploited	Highly over-exploited	Over-exploited	Suitable	Suitable	Suitable

Figure 3. Suitability of agricultural land uses. Intersection between agricultural uses and suitability (table of equivalences 04).

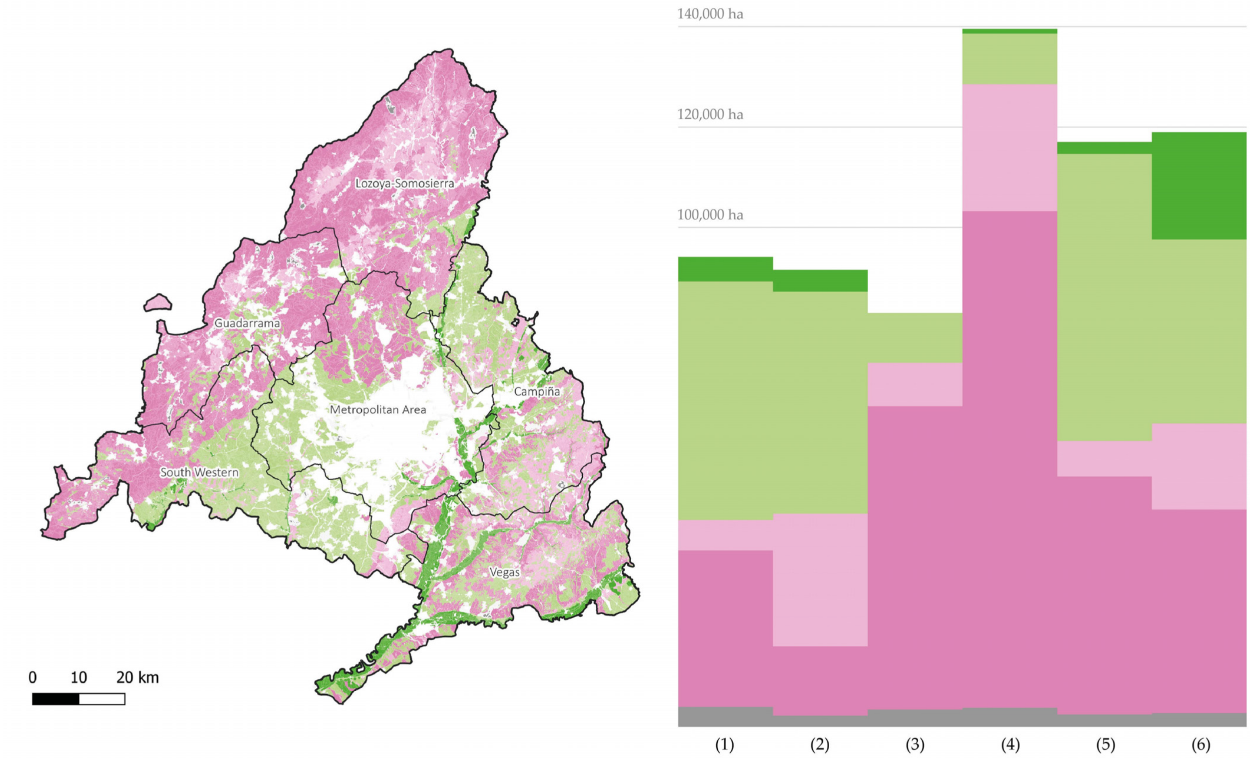
- Highly over-exploited. The soil is unable to sustain crop production without experiencing the long-term degradation of quality. In these plots, agricultural activities are performed in low- and medium–low-quality soils that are only appropriate for non-agricultural uses or for permanent crops such as olive groves or vineyards.
- Over-exploited. The soil is unable to sustain crop production without experiencing long-term degradation in quality. In these plots, agricultural activities are performed in low-, medium–low- and medium-quality soils subject to restrictive conditions, limiting the crops that can be grown.
- Suitable. The soil is able to sustain crop production without compromising its quality in the long term. In these plots, agricultural activities are adapted to soil quality.
- Under-exploited. The soil is able to produce more demanding crops. In these plots, agricultural and non-agricultural activities are performed in soils with a better quality than that which such crops require.

- Highly under-exploited. The soil is able to produce much more demanding crops. In these plots, non-agricultural activities are performed in high- or medium-quality soils.

3. Results

3.1. Soil Quality for Agricultural Uses

The agrological capacity of each region depicted in Figure 4 is described below based on the map of agrological classes and is related to the topographical, geological and edaphological characteristics explained in the document 'Characterisation of the agricultural regions' [41].



Soil quality for agricultural uses	(1) Metropolitan Area	(2) Campiña	(3) Guadarrama	(4) Lozoya-Somosierra	(5) Southwestern	(6) Vegas	Total
High	4983	4352		923	2342	21,254	33,853
	5.29%	4.75%	0.00%	0.66%	2.00%	17.87%	5.26%
Medium	47,420	44,196	10,011	10,174	57,164	36,729	205,694
	50.34%	48.27%	12.06%	7.29%	48.88%	30.89%	31.93%
Medium–low	6077	26,466	8521	25,215	6975	17,101	90,355
	6.45%	28.91%	10.27%	18.07%	5.96%	14.38%	14.03%
Low	31,229	13,771	60,494	98,920	47,466	40,552	292,431
	33.15%	15.04%	72.88%	70.88%	40.59%	34.10%	45.40%
Not suitable	4499	2772	3974	4321	3005	3280	21,852
	4.78%	3.03%	4.79%	3.10%	2.57%	2.76%	3.39%
Total	**94,208**	**91,557**	**83,000**	**139,553**	**116,952**	**118,916**	**644,185**
	100.00%	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Figure 4. Soil quality for agricultural uses. Mapping and distribution of the surface areas of soils suitable for agricultural uses in the Madrid region.

In the metropolitan area, half of the soils have a medium quality for agricultural use and 33% have a low quality.

Comarca Campiña, with almost half of the land of medium agricultural quality, has relatively good agrological capacity. In *Comarca* Guadarrama, the soils are poor for cultivation, with almost 73% of the land of very low agrological capacity.

Comarca Lozoya-Somosierra is characterised by poor soils for cultivation, and 71% of the land has very low agrological capacity. The Southwestern *Comarca* has a dual agrological character, with half of the area being of medium agricultural quality and 40% being of low agricultural quality. *Comarca* Las Vegas is the area with the highest percentage of soils with good agrological capacity (18%) of the whole region, but it also has soils with low (34%), medium (31%) and medium–low (14%) capacity.

In sum, there is a close correlation between topography, geology and agrological capacity. As we have seen, three diagonal bands can be distinguished in terms of the quality of agricultural land: The mountainous regions, which run along the western part of the Community, have the least suitable soils for cultivation; the central band has the best conditions and is where the main population centres are located. Urban growth has taken place at the expense of good quality land, the most significant case being the metropolitan area. Finally, in the south-east, there is a mixture of qualities, as the main fertile plains are here, but the rest of the land is not of good quality.

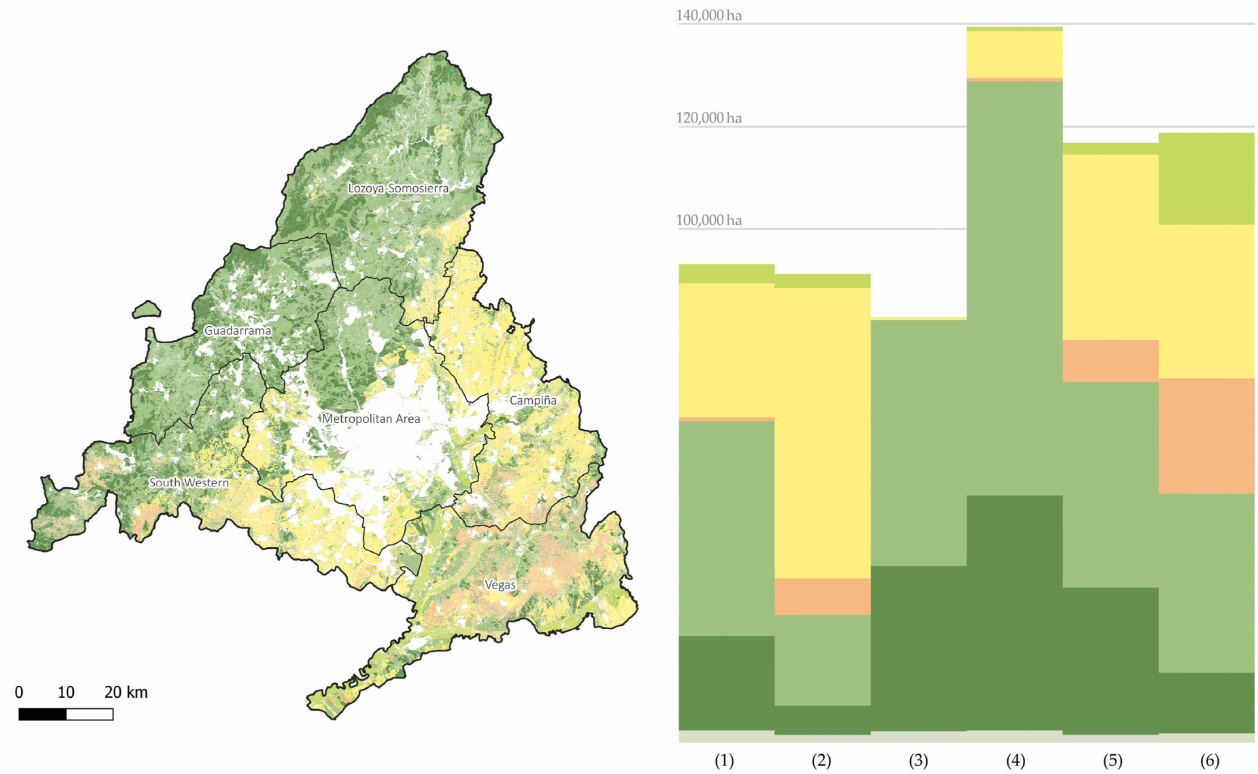
3.2. Distribution of Agricultural Uses

In terms of land use and farm orientation, the Community of Madrid has two agricultural *comarcas*, two livestock *comarcas*, one mixed and one with a metropolitan character; in the east of the Community there are two *comarcas* with a strong agricultural component (Figure 5). They share characteristics with the Castilian plateau and, more specifically, with La Mancha. They are the Campiña, with thirty-one municipalities, and Las Vegas, with twenty-eight municipalities. The Campiña is dominated by non-irrigated arable crops, which occupy 62% of the land and account for almost a third of all non-irrigated arable crops in the Community. Pastures and grazing land are also relatively important, accounting for 20% of the area. The *Comarca* de Las Vegas, on the other hand, includes both the mesetas and the valleys of the Tajuña, Jarama and Tajo rivers, an important part of which is included in the South-East Regional Park. These riverside areas are the most fertile and make it the only region where irrigated crops have a significant presence, occupying 15% of the land and accounting for 65% of the total irrigated land in the region.

Two other *comarcas* are livestock and forestry areas, located in the north and west on mountainous terrain of high environmental value, and the distribution of land use is very similar in both. In both Guadarrama and Lozoya-Somosierra (in the north), just over half of the land (57%) is devoted to pastures and meadows, and a third (38% and 32% respectively) to woodland. In Lozoya-Somosierra, there is some presence of dry crops (almost 1000 hectares), while in Guadarrama, they do not even cover 400 hectares.

The Southwestern region is more diverse, with fertile lowlands, cereal plains and foothills devoted to livestock farming.

Finally, there is an urban area, the metropolitan area, where the presence of forests and pastures is comparatively important, sometimes in areas where agriculture has been abandoned.

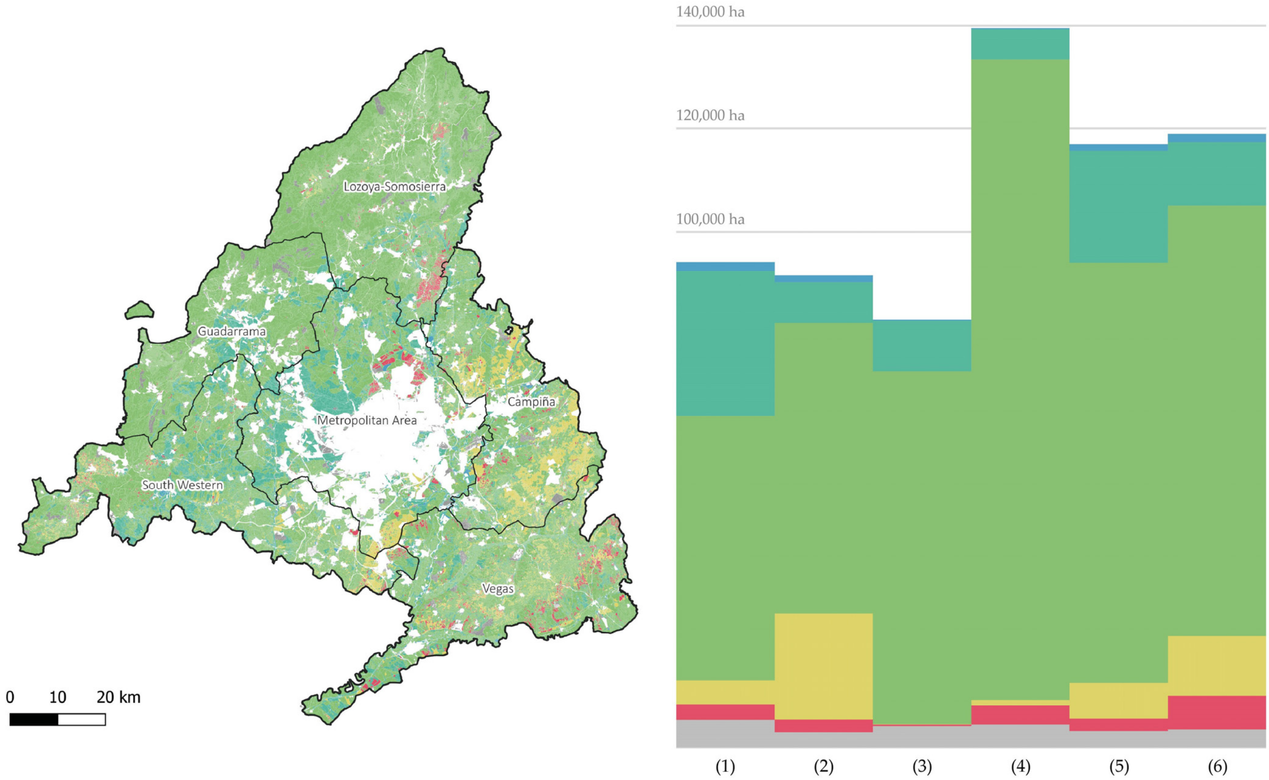


Categories of agricultural uses	(1) Metropolitan Area	(2) Campiña	(3) Guadarrama	(4) Lozoya-Somosierra	(5) South Western	(6) Vegas	Total
Permanently irrigated crops	3772	2675	77	824	2261	17,833	27,442
	4.00%	2.92%	0.09%	0.59%	1.93%	15.00%	4.26%
Non-irrigated arable crops	26,118	56,532	385	9135	36,109	30,044	158,323
	27.72%	61.75%	0.46%	6.55%	30.88%	25.26%	24.58%
Permanent crops	752	7024	9	687	8242	22,415	39,128
	0.80%	7.67%	0.01%	0.49%	7.05%	18.85%	6.07%
Grasslands and pastures	41,814	17,746	47,913	80,715	40,018	34,809	263,015
	44.38%	19.38%	57.73%	57.84%	34.22%	29.27%	40.83%
Forests and scrubs	18,245	5,551	32,067	45,685	28,500	11,692	141739.8948
	19.37%	6.06%	38.64%	32.74%	24.37%	9.83%	22.00%
Bare lands	2442	1603	2277	2386	1655	1940	12,304
	2.59%	1.75%	2.74%	1.71%	1.42%	1.63%	1.91%
No data	1066	425	271	121	167	183	2233
	1.13%	0.46%	0.33%	0.09%	0.14%	0.15%	0.35%
Total	**94,208**	**91,557**	**83,000**	**139,553**	**116,952**	**118,916**	**644,185**
	100.00%	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Figure 5. Categories of agricultural uses. Mapping and distribution of surface areas by agricultural uses and comarcas.

3.3. Suitability of Agricultural Land Uses

In all the *comarcas*, the majority of agricultural uses are well adapted to the agroecological capacity of the land (Figure 6), but with notable differences between the *comarcas*. The *comarcas* with a better balance between uses and agricultural capacity are those in the mountains, Lozoya-Somosierra and Guadarrama (both over 80%). These are the *comarcas* with the worst conditions for agriculture, since the topography itself, the poor soils and the harsh climate have traditionally oriented the uses towards livestock farming, with a predominance of grassland, pastures and forests. In Lozoya-Somosierra, there is some over-exploitation in the extreme south-east, in the fertile lowlands of the Jarama, with permanently irrigated crops.



Suitability of agricultural land uses	(1) Metropolitan Area	(2) Campiña	(3) Guadarrama	(4) Lozoya-Somosierra	(5) Southwestern	(6) Vegas	Total
Highly under-exploited	1769 1.88%	1308 1.43%	170 0.21%	208 0.15%	1238 1.06%	1564 1.32%	6,257 0.97%
Under-exploited	28,173 29.91%	7837 8.56%	9828 11.84%	5896 4.22%	21,649 18.51%	12,274 10.32%	85,658 13.30%
Suitable	51,222 54.37%	56,361 61.56%	68,498 82.53%	124,240 89.03%	81,518 69.70%	83,431 70.16%	465,271 72.23%
Over-exploited	4672 4.96%	20,686 22.59%	104 0.13%	1099 0.79%	7010 5.99%	11,605 9.76%	45,176 7.01%
Highly over-exploited	3035 3.22%	2454 2.68%	292 0.35%	3684 2.64%	2397 2.05%	6589 5.54%	18,451 2.86%
Not suitable	5337 5.66%	2911 3.18%	4107 4.95%	4426 3.17%	3139 2.68%	3453 2.90%	23,372 3.63%
Total	**94,208** **100.00%**	**91,557** **100.00%**	**83,000** **100.00%**	**139,553** **100.00%**	**116,952** **100.00%**	**118,916** **100.00%**	**644,185** **100.00%**

Figure 6. Suitability of agricultural land uses. Mapping and distribution of surface areas.

On the other hand, in both the Las Vegas and the Southwestern regions, about 70% of the land is used according to its capacity. In Las Vegas, 15% of the land is over-exploited, mainly along the course of the Tajuña, while in the Southwestern *Comarca*, there is a notable presence of land that does not use all its productive capacity (almost 20% of the total), that is, land that could be used for crops but is used as pasture, forest or scrub.

Even more remarkable is the presence of under-utilised land in the metropolitan region, where 30% of the land is used for less than its productive capacity. These areas are located near the city of Madrid and the residential areas in the west, where there are forests. Some have historically been hunting grounds. The region also has almost 10%

over-exploited soils in the extreme south-east, with crops and irrigation on unsuitable land, and in patches in the north, with crops on land suitable for pasture or forestry.

Finally, some of the largest areas of over-exploited soils are concentrated in the Campiña area, accounting for almost a quarter of the *comarca's* area and almost a quarter of the region's total. These are non-irrigated arable crops grown on poor soils.

4. Discussion

Building on the results of the analysis conducted and the literature references on similar studies, we discuss firstly the methodological innovations and their possible improvements. Then, we address the contributions of the case study and to what extent the results can be used to inform public policies and land planning, defining recommendations on land use location. We conclude by reflecting on how urban planning regulations can be developed for the appropriate land planning and management of agricultural systems.

The majority of agricultural land suitability analyses are GIS-based, using overlay mapping, multi-criteria evaluation and more recently artificial intelligence methods, taking into account bio-physical requirements but rarely considering socio-economic and technical requirements [17]. These analyses include numerous aspects affecting the agricultural suitability of the soil, the most common of which are slope, organic matter, soil texture, soil depth, erosion, water holding capacity, rainfall and temperature [19,20,44–47]. Some methodologies achieve high levels of accuracy by adapting the assessment to the requirements of specific crops [48,49], providing monitoring and updating of the land evaluation [50] or modelling land capability and yield reduction in climate change scenarios [51–53]. The methodology applied in this study does not require a multi-criteria analysis because the soil quality information comes from an official cartographic database including climatic, hydrologic, soil and topographical parameters (climate, erosion, excess water in the soil, root zone conditions, tilling techniques and, in the case of irrigated land, the quality of irrigation water).

The innovation of this methodology lies in its delineation of five suitability categories, derived from the intersection of seven land use categories and four soil quality classes. This approach is regarded as a methodological contribution, as it facilitates the synthesis of highly detailed information, rendering it comprehensible and readily applicable in the domain of spatial planning. Additionally, the methodology is easy to replicate, since it is based on two official and open-access databases, available for the entire Spanish territory. Similar databases also exist in other countries, with which information the proposed methodology could be adapted and replicated. However, it would be very interesting to develop a more dynamic tool that would allow for the visualisation of future scenarios in which variations in soil quality and land use could be introduced. On the one hand, regarding land suitability, the impacts of climate change and adaptive responses [54] would be incorporated, in addition to the possibilities of soil improvement or degradation due to agricultural management (sustainable management or prolonged over-exploitation). On the other hand, for land uses, land changes in area with crops adapted to soil quality and the recovery of under-utilised land could be mapped. This may form the basis for calculating supply capacity in different scenarios. In this sense, the main problem is that land use cover maps do not reflect agricultural practices despite their major impact on compliance with carrying capacity. Other complementary data sources could be integrated, such as the agricultural census, SIGPAC maps of agricultural landscape elements (hedgerows, forest islands, etc.) or biomass productivity [55].

The databases used (SIOSE, 2017, and Agrological Map, 2012) present problems of obsolescence that affect the accuracy and relevance of the spatial planning, especially in areas undergoing rapid change, such as the case study area. The lack of a more recent source of land occupation data prevents the reflection of recent changes. Similarly, considerations of productive capacity based on data prior to this period may not take into account changes over the past decade, whether due to degradation from agricultural over-exploitation or improvements from sustainable practices. In addition, these databases do not take into account the effects of climate change, which can alter soil productivity and its suitability for different crops. In order to carry out effective territorial or urban planning, it is essential to have up-to-date databases that accurately reflect the current situation and allow for the modelling of future scenarios. These databases must take into account key challenges such as urbanisation, climate change and the need to protect agricultural land.

One of the main results of our analysis is that the territory under analysis exhibits a widespread adaptation of crops to the soil's quality. This phenomenon implies a use of natural resources that aligns with the soil's productive capacity. This observation suggests that farmers possess a high level of knowledge regarding the territory and soil management, even within the context of industrialised agriculture. These results are consistent with those of a study carried out in another Spanish region located in the Ebro valley [25]; despite differences in methodology, in both cases, the results show the existence of a significant relationship between crops' location and land capacity, especially for crops with a higher demand for soil and water resources. The high knowledge of farmers regarding the capacities of the territories can be deduced, which leads to the maintenance of soil-adapted crop types, which generate characteristic cultural landscapes. These results are also consistent with other studies developed at the national scale that depict extensive areas where productivity and ecosystem services are well balanced [55,56]. Despite the possibilities of intensification by chemical and technological inputs, soil capacity (based on climate and soil conditions) remains an important constraint for production.

Assessment tools such as the one developed here are necessary to adapt land policies and planning to the reality of the territories and, in particular, to the risks of land abandonment, degradation and over-exploitation. The suitability categories defined in our methodology serve to highlight trends occurring in the territory. Thus, in soils mapped as under-exploited, it can be deduced that abandonment dynamics are occurring, as these soils are good for agricultural use but are currently covered by natural vegetation. In the opposite direction, soils classified as over-exploited are indicative of a use that will degrade the territorial resources in the medium term. The use of GIS can help to accurately identify different situations and to define land use and management policies. This has been conducted in Sicily using a spatial data infrastructure to concentrate the application of agro-environmental and soil protection measures to the area where the expected benefits are maximised [57].

The methodology developed is intended to be useful for land planners in identifying priority areas for agricultural protection and in defining the compatible land use conditions in agricultural areas. As De la Rosa et al. [58] point out, there is a difference between land planning and land management. The former is aimed at the regional level, and its determination regarding land use can be supported with land suitability models. Land management planning is the second phase after land use planning; it is aimed at the farm level and should be informed by land vulnerability due to risks such as soil erosion or contamination. The practical application of the methodology provides new insights into agricultural land, facilitating its integration into the field of spatial planning by correlating the suitability of uses with guidelines for the conservation and rehabilitation of agricultural land. This approach makes it possible to introduce into spatial planning the consideration of suitable uses for medium-quality soils, overcoming the idea that only high-quality soils deserve protection. Furthermore, planning can be oriented not only towards soil protection but also towards the definition of strategies for recovery, regeneration, etc. We have mapped different situations according to the correspondence between land use and soil suitability, from highly over-exploited to highly under-exploited land. This suitability assessment can conclude recommendations on land use and propose different strategies for agricultural areas with differentiated characteristics.

As synthesised in Table 1, for highly under-exploited or under-exploited land, where plots are large enough to make agriculture viable, as is the situation in the Southwestern region, the main recommendation is the introduction or recovery of appropriate crops. Areas with high soil quality and water availability should be designated as 'priority areas for horticulture', while areas with medium soil quality should be 'areas for recovering arable crops'. However, depending on several factors, other uses could be a better choice for these lands, such as carbon sequestration or nature restoration [59]. Information on current use is not enough; in order to recognise the reasons for under-exploitation or abandonment, information must be gathered on, at the least, the geographical location, land ownership, dimensions and socio-economic conditions of the farms. With this characterisation, proposals regarding land use and management conditions can be defined more precisely, from the creation of land banks for agricultural entrepreneurship and the promotion of short circuits to rewilding.

Table 1. Land planning recommendations depending on the suitability of agricultural land uses.

Suitability of Agricultural Land Uses	Recommendations for Land Planning
Highly under-exploited and under-exploited	'Priority areas for horticulture' or 'areas for recovering arable crops' depending on soil quality and water availability.
Suitable	'Protected agricultural areas' + inventory of agricultural areas (defining allowed land uses and management systems).
Over-exploited and highly over-exploited	'Ecological regeneration areas', defining actions for land conservation and improvement.

For suitable agricultural land uses, which are predominant in all the *comarcas*, the main objectives are to conserve land use and maintain soil quality. For this purpose, 'protected agricultural areas' should be designated. A delimitation of geographically differentiated areas is required based on topographic and landscape features; afterwards, information about the current management systems and the main vulnerability factors should be collected. In this way, an inventory of agricultural areas and their geographic locations can be developed and used as a basis for the definition of allowed land uses and management systems.

For over-exploited and highly over-exploited land, the proposed course of action is to limit excessively demanding land uses and to restore soil quality conditions. In this sense 'ecological regeneration areas' should be designated in order to reverse the pressure on natural resources, defining actions for land conservation and improvement. This can be linked to an agro-ecological transition strategy [55]. Measures aimed at restricting crops, especially permanently irrigated crops, in medium- or medium–low-quality soil areas, as well as non-irrigated arable crops in medium–low- and low-quality soil areas, should be defined. Reforestation with appropriate shrub and forest species or a change from arable crops to pastures may be the best strategy for the latter areas, as De la Rosa et al. [58] conclude for this kind of imbalance in suitability. The main limiting factors for soil suitability in the Madrid region are related to erosion, soil depth, water retention and slopes. Therefore, crops and natural species with a greater soil holding capacity and better management practices on slopes are needed.

The suitability analysis conducted is a good starting point to identify areas of interest. However, the definition of measures and conditions for planning requires a more territorialised analysis. For example, our results show a large area of under-exploited land in the metropolitan district, which corresponds to the Monte del Pardo demarcation, a protected area where it would not make sense to recommend agricultural intensification for historical, heritage and regulatory reasons that characterise its use for forestry. Due to mismatches such as this, a second step in the analysis should distinguish different situations according to agricultural units and structures, legal protections, accessibility and proximity to urban areas, infrastructure, distribution nodes, land tenure and socio-economic processes. The multi-criterion analysis conducted by Romano et al. [60] to identify sites for the development of agro-environmental tourism activities in the Italian Monte Sant'Angelo municipality offers some interesting insights on how to conduct more complex approaches, although the municipal scale of their analysis differs from our regional and district scale. A more complex approach, taking into account the reasons for protection or the contribution of the territory to the ecosystem, would offer useful perspectives for further extending the research by linking it to planning issues as set out in the Spanish legal framework.

5. Conclusions

It can be concluded that agricultural issues should not be analysed in isolation or independently of other factors when defining spatial planning. Agriculture, as a land use, interacts in a complex way with its environment, and its planning must take into account not only productivity and efficient resource management but also the wider impacts that agricultural activities cause or may cause, especially in the context of rapid urbanisation and climate change. Integrating environmental considerations into spatial planning is essential to create a more comprehensive and sustainable planning framework. Regional and urban planning plays a key role in soil protection by efficiently managing land use and avoiding the overconsumption of agricultural land, which is essential to ensure food security and resilience in the face of global change. In this sense, balance must be sought between the demands of urban expansion and the need to maintain the productivity and health of agricultural land, which is key to long-term sustainability.

The example of the Madrid region shows how agricultural features can and should be integrated into urban and regional plans, thereby increasing their effectiveness in protecting valuable agricultural areas. This approach also facilitates the more effective management of agricultural and natural resources. As a result, planning is not limited to compliance with urban regulations but also aims to actively conserve the natural and agricultural environment.

Spatial planning must therefore evolve towards a more integrated approach that reconciles agricultural production, urbanisation and environmental protection. The adoption of innovative methodologies, such as the one described in this paper, could provide planners with the necessary tools to address the challenges posed by urban expansion and the loss of agricultural land while promoting development models that enhance sustainability and resilience at all levels.

Supplementary Materials: The following supporting information can be downloaded at: https://drive.upm.es/s/eWXJrhyBdhgCX7f (accessed on 5 January 2025). Figure S1 (Methodology scheme) includes four tables of equivalences used in data processing in order to evaluate suitability for agricultural uses. These four tables make possible to replicate this methodology. Tables S1 and S2 assign categories of agricultural uses to SIOSE database; Table S3 establishes the equivalence between agrological classes (1–8) and the level of soil quality for agricultural uses (high, medium, medium–low); and table of equivalences 04 is similar to Table S1 but prepared for data assignment This work have been produced using EasyData Transform.1.47 and QGIS Desktop 3.36 software.

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