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Use of Edaphic Bioindicators to Mitigate Environmental Impact and Improve Agricultural Research and Training

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Abstract: The world is currently experiencing unsustainable development, which poses significant risks to global society. In response, there is a growing advocacy for sustainable development across all sectors, driven by social resilience. This shift is fostering substantial socio-environmental tensions. However, the combined power of scientific research and social education has the potential to reverse this trend. Transitioning from an unsustainable territorial model to a sustainable one is both feasible and economically profitable. This transition can be achieved through knowledge of soil bioindicators, which provide valuable information about soil nutrient content. By understanding these indicators, nutrient inputs can be tailored, reducing or eliminating pollutants such as excessive fertilizers, herbicides, and pesticides. Training experts and raising social awareness through education on new research are essential steps in this process. For decades, it has been recognized that globalization, industrialization, and population growth have driven unsustainable development, leading to degraded agroecosystems. To address this issue, government institutions are promoting sustainability through ecological agriculture and CO_2 reduction, both of which can be supported by the use of soil bioindicators.

Keywords: sustainability; pollution; economy; research; teaching; conservation

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1. Introduction

The drive for high agricultural production to meet the demands of a growing world population has led to uncontrolled and unsustainable development. This has overwhelmed government regulation and, combined with a lack of environmental education and training, is causing serious damage to ecosystems, socio-environmental systems, economies, and public health [1]. A major factor contributing to this damage is the excessive and improper use of chemical agents in agriculture, which infiltrate the food chain [2]. Despite various reports and regulations, effective control mechanisms to mitigate these impacts are still lacking.

The interplay between agricultural intensification, population growth, insufficient government regulation, and inadequate eco-education has resulted in significant harm to ecosystems. Authors like Raskin [3] highlight that without greater ecological awareness and education, humanity is on a trajectory toward self-destruction through unsustainable development.

The Official Journal of the European Union (EU), through Commission Implementing Regulation (EU) 2019/2072 of 28 November 2019) [4], stipulates that “passports and phytosanitary certificates” are required for the introduction and movement of plant products. However, this regulation primarily addresses the transport of seeds and plants for planting, without adequately covering the need to control the entry of non-native species. These invasive species can disrupt ecosystems and crops, underscoring the importance of assessing their impact in various contexts.

Commission Implementing Regulation (EU) 2022/959 of 16 June 2022 [5], which amends Annex VII of Implementing Regulation (EU) 2019/2072, introduces new requirements for the entry of certain fruits, including *Capsicum* (L.), *Citrus* L., *Citrus sinensis* Pers., *Prunus persica* (L.) Batsch, and *Punica granatum* L., into the European Union. The aim of this regulation is to prevent the introduction and spread of pests affecting these plants.

With regard to pesticides, the regulations specify that their application is prohibited for the general public [6]. More recently, the Spanish Ministry of Agriculture, Fisheries, and Food issued Royal Decree 387/2021 on 1 June, published in BOE nº 151 on 25 June 2021. This decree regulates the Official Phytosanitary Certification regime for the export of plants and plant products and amends the Royal Decree 50/2005 of 21 January. The amendment strengthens protective measures against the introduction and spread of harmful organisms within national territory and EU territories, as well as for their export and transit to developing countries [7]. The decree also outlines that only qualified professionals, such as agricultural engineers, agricultural technical engineers, forestry engineers, and forestry technical engineers, are authorized to issue the “Phytosanitary Certificate”.

The Ministry of Health and Social Policy of Spain, through the Royal Decree 830/2010 of 25 June, establishes the regulations for training individuals to conduct biocide treatments. Additionally, a thorough socioeconomic and health assessment of habitat loss is essential, requiring the expertise of suitably qualified professionals [8].

This Royal Decree does not address public health concerns. While the personnel are qualified under Spanish legislation, their training appears insufficient to assess the impact of chemical agents on human health, as the curricula of the relevant degrees lack this focus. Therefore, we propose, as a fundamental objective, the development of a territorial model that is free from social and economic tensions and fully respects the natural environment.

Most countries adhere to an unsustainable economic development model, which, combined with climate change [9,10], leads to significant deforestation, agricultural damage, and adverse health effects [11,12]. The excessive use of chemical pollutants in agriculture contaminates the food chain, often exceeding safe levels. Although some contaminants may fall within WHO standards, they can accumulate in the body or may take a long time to be eliminated by the body [13,14], increasing the risk of developing tumors.

The irresponsible contamination of soil, water, and biota by chemical products, along with the spread of invasive species, exacerbated in part by climate change, contributes to declining crop yields and reduced agricultural production [15–17]. Soil contamination by heavy metals in agricultural soils is not only a serious environmental problem threat but is also a direct risk to human health, as noted by Shen et al. [18]. This contamination, combined with a growing world population, is driving severe social and economic crises due to compromised food safety and security.

These chemicals enter the food chain and have been detected in the blood and breast milk of pregnant women, as well as being identified in studies involving young people, where a rise in genetic malformations has been observed, according to Torres and Capote [11]. These authors also emphasize the need for greater demands in terms of education. Moreover, the number of the aforementioned genetic anomalies is increasing in developing countries.

The deterioration of ecosystems caused by invasive exotic species, global climate change, particularly affecting the Mediterranean basin [19–33], and the decline in pollinating insect populations due to excessive pesticide use [34], is significantly reducing agricultural production. Of particular concern is the loss of yield production in crops such as coffee, as highlighted by Bilen et al. [35], and the similar decline in olive cultivation in Mediterranean regions. This issue is further exacerbated by the establishment of olive cultivars in areas unsuitable for their growth [36].

As conflicts, climate crises, and the degradation of land and water resources intensify, greater pressure is placed on agricultural and marine livelihoods in developing countries, jeopardizing food security and leading to severe social conflict [37,38]. This situation underscores the need to better understand how varying vulnerabilities impact food security outcomes. With minimal or no government control mechanisms in place, there is a need to reverse these trends by adopting a sustainable development model. The implementation of such a model is possible as a result of new agricultural research that has been collected in various environmental studies [15–20], which present emerging developments in agriculture. These studies reflect the significant advancements seen in vegetation science, particularly in Europe and Spain [39–45].

Consequently, several authors have proposed models of sustainable development that can be integrated with social resilience to address ongoing environmental challenges.

Yet this effort requires highly qualified personnel with strong management skills, motivation, and a commitment to implementing sustainable development models, including the creation of green economy-based companies [46]. To achieve this change, these experts must be trained in various environmental fields, such as in managing invasive species and conducting research on exotic plants and soil pollutants, areas of research that should be actively promoted.

Sustainable development must be proactively promoted, and it is essential for experts to perform comprehensive studies on the various physicochemical parameters that affect environmental quality and health [47].

Severe climate change is increasingly impacting various territories of the planet, especially in Mediterranean environments. Addressing issues related to water scarcity, pollution, and misuse is crucial for both developed and developing countries [48]. In fact, there is a growing recognition of the importance of ecosystem services as basic and cultural resources for populations. Additionally, the conservation of genetic resources, which have dramatically declined over the past 50 years, is becoming a top priority [49,50]. Thus, it is vital for societies to preserve habitats and ecosystems by reducing deforestation, preventing fires, and minimizing land and water pollution to safeguard both ecosystem health and public well-being [50,51].

An example of valuable ecosystemic habitats is cork oak forests, which serve as a significant socio-economic resource in the Mediterranean regions of Spain, Italy, Portugal, and North Africa. Their fire resistance allows them to act as natural barriers against wildfires [52]. However, in some Mediterranean areas, fires lead to severe erosion, causing the loss of native vegetation and the proliferation of *Juniperus oxycedrus* [53].

The EU habitat directive (Directive 92/43/EEC) [54] is considered a cornerstone of nature conservation in Europe. Nevertheless, its effectiveness could be improved as it exhibits ambiguity in certain areas across European countries [55]. While the directive contemplates the diversity of habitats in Europe, it has overlooked many natural and semi-natural grasslands, particularly those found in agricultural areas. This oversight stems from the directive's focus on species of conservation interest, neglecting the ecological value of grasslands as valuable indicators of soil nutrients [56]. Consequently, these grassland habitats are vulnerable to local practices, including the use of chemical agents—herbicides and pesticides—by untrained individuals, leading to significant health risks and environmental damage [12–14,57].

Nonetheless, in recent decades, considerable progress has been made in understanding habitats through detailed description, mapping, and evaluation [58]. Advances include phytosociological descriptions of habitats and the related efforts to conserve them, either due to the presence of endangered species or their significance as ecosystem services. This has led to the development of methodologies such as the study of edaphic bioindicators, which are crucial for habitat research. Additionally, the decline in agricultural production and the subsequent poverty in rural areas further underscores the need for this research [59–61]. Therefore, the aim of this study is to provide researchers and university teachers with a comprehensive model of territorial management that can support both sustainable development research and teaching.

2. Materials and Methods

In light of the strong scientific progress seen in vegetation science, both ecologically and descriptively, we focused on the study of edaphic bioindicators [32,37,52]. For this purpose, we carried out a study of the grasslands present in olive groves in Spain. Sampling plots were originally selected between 2005 and 2007 by Cano Ortiz (Figure 1). The edaphic parameters were measured, and plot biodiversity was assessed, in order to establish a correlation analysis between nutrient levels and species abundance [62]. In addition, floristic sampling was conducted according to the phytosociological methodology that is widely employed in Mediterranean countries.

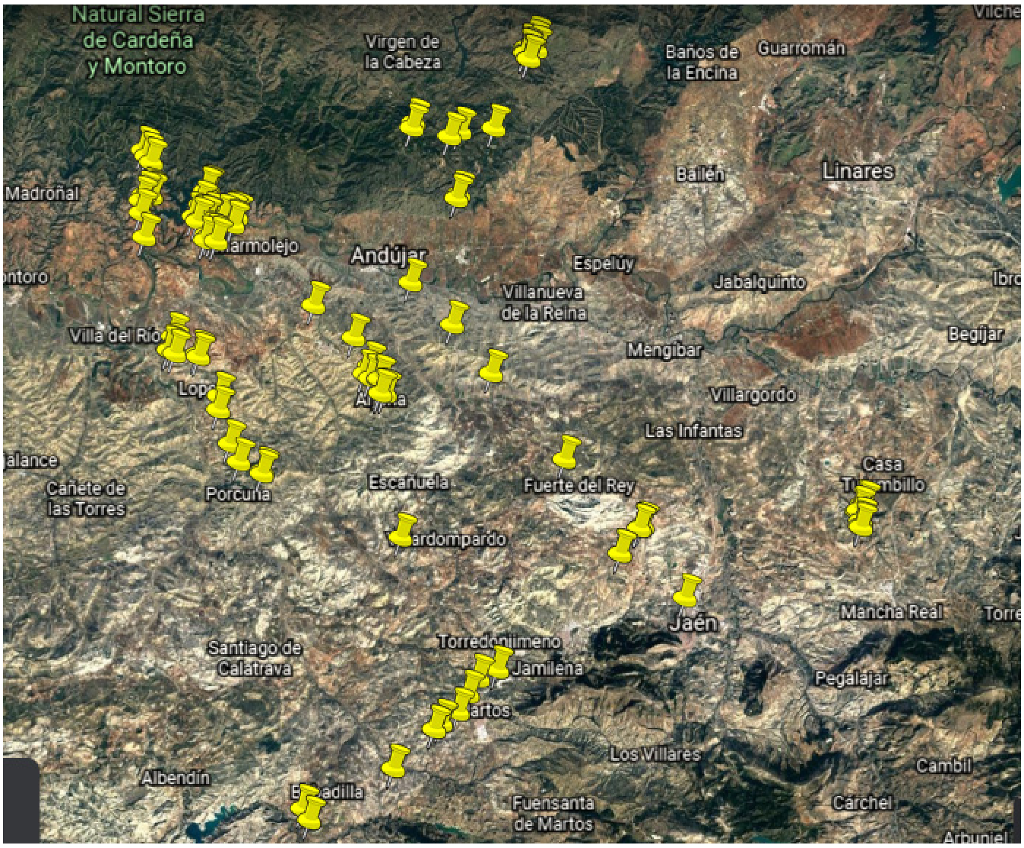

Figure 1. Location of the experimental sampling plots. Sampling areas were located in sites with dominant edaphic indicator species.

Plots were selected in olive-growing areas, based on the ecological and physiognomic characteristics of the plant community. During phytosociological sampling, data were collected using GPS for UTM coordinates, including the depth of the root systems of the dominant species, soil sampling, orientation, slope, altitude, plot coverage percentage, and the average height of the dominant species. To determine the sampling area for each community, we previously established the minimum required area. For each community studied, 20 samples were gathered from various locations with similar ecological and physiognomic conditions. In the edaphic study, the same floristic sampling plots are used, with samples taken from the depth of the root systems of the dominant species. Sixteen edaphic parameters were then analyzed.

The plots were chosen according to the dominant species of the community, focusing on those with significant representation in the study area and widespread distribution across the Mediterranean. For example, communities dominated by *Hordeum leporinum*, *Malva neglecta*, *Taenietherum caput-medusae*, and *Glebionis discolor* were chosen to ensure that the model could be extrapolated to other Mediterranean territories.

Years later, between 2018 and 2021, Leiva repeated the research using the same sampling plots in Spain and employing the same methodology as Cano Ortiz [63]. These follow-up samples were collected to compare with those from the original study, providing a comparative analysis of diversity loss over a 13-year period. Additionally, the study introduced the importance value index (IVI), a metric used to classify and quantify the phytosociological importance that a species presents within an association. It is calculated using the following equation:

$$\mathrm{IVI} = \mathrm{A}\% + \mathrm{Dom}\% + \mathrm{Frec}\%.$$

where: A% = relative abundance, Dom% = relative dominance, and Frec% = relative frequency.

The IVI parameter is one of the most widely used indices in the analysis of tropical forest ecosystems, although it is infrequently used for this purpose. Its main advantage is that it is quantitative and precise. Furthermore, it does not lend itself to subjective interpretation. In addition, it provides a large amount of information within a relatively short time. It supports statistical analysis and expands knowledge of the flora. The method not only provides an importance index for each species but also yields essential quantitative elements for ecological analysis, such as density and biomass, both per species and per plot. The latter is a basic character for interpreting the productivity of a site, which is highly dependent on bioclimate and soil resources.

To calculate the species IVI, it is necessary to transform the Van der Maarel values into coverage estimates. In this sense, the following equivalence is used for this conversion (see Table 1).

Table 1. Equivalence between phytosociological indices, Van der Maarel values, and land coverage. PI = Phytosociological indices.

PI	Maarel	Coverage (%)
r	1	3
+	2	6
1	3	12
2	5	25
3	7	45
4	8	65
5	9	85

The type of herbicide used as a cause of the floristic loss of the grassland was analyzed. Statistical techniques were applied in the two study periods using XLStarts, 2024.3 Community Analysis Package III, Past.exe and MATLAB 7.1., Pajek 1.10., and Weka, after transformation of the phytosociological indices to those of Van der Maaler.

Among the statistical techniques used, we applied phytosociological colocalization networks, Bayesian probabilistic networks, and classification by expert systems (decision trees), which are programs that simulate human reasoning.

Expert systems are particularly useful in situations or problems where conventional methods cannot provide a standard solution. The purpose of these knowledge representation techniques is to generate a schema model, whereby a human expert relates a set of observations and experiences to a result or conclusion. Once the schema has been established, the expert in question will follow a certain reasoning mechanism that will lead to a result, and, depending on this, the expert will take a certain decision on how to act in the face of the problem that was initially posed. Expert systems include both decision trees and artificial neural networks, although, in this work, we used only decision trees.

For the analysis of the presence of the most generalist species in the different associations, phytosociological colocalization networks were used. Graphs were created, in which the nodes correspond to the characteristic species of the associations and the arcs that connect them indicate that both species colocalize in the same association. The matrices used, therefore, contain pairs of data corresponding to co-occurring species (colocalization).

The program Pajek 1.10: http://vlado.fmf.uni-lj.si/pub/networks/pajek/ (accessed 8 January 2008) was used for the elaboration of the networks. The representation algorithm was the Kamada–Kawai algorithm. The species of the same association are shown with circular nodes of the same color and are located at the periphery of the graph, except for those that are located in more than two associations, which are located in the center and whose nodes are of the box type and white in color. All the nodes have a size relative to the number of associations in which they are placed, a number that is also indicated next to the name of each species.

Bayesian networks offer a probabilistic approach to modeling and managing uncertainties. They are based on probability theory (Bayes' theorem) and graph theory to represent complex relationships in various fields. For instance, Bayesian networks have been applied to deal with the uncertainty that characterizes the fluctuations of financial markets, medical diagnoses, and natural ecosystems. Still, their use in plant biology, particularly in studying plant–soil relationships, has been limited. Our study represents a novel application of Bayesian networks.

One of the approaches we have employed as a technique for classifying plant–soil relationships, and their representation, has been the elaboration of decision trees. A decision tree is a prediction model used in the field of artificial intelligence, where, given a database, logical diagrams are constructed, which serve to represent and categorize a series of conditions that occur successively, and these are used for the resolution of a problem. A decision tree has inputs, which may be an object or a situation described by means of a set of attributes, and from these, it returns an answer taken from the inputs that can be used as a decision criterion. The values that the inputs and outputs can take can be either discrete or continuous. In this work, the decision trees were obtained using the data mining program Weka: http://www.cs.waikato.ac.nz/ml/weka/ (accessed 8 January 2008) [63].

3. Results

In our study of the plots, minimum areas ranging from 0.5 to 2 m^2 were determined, depending on the type of pasture or grassland. A total of 313 plant species were identified through floristic analysis. For the edaphic analysis, the guidelines specified in BOE 246, Order of 17/09/1981, were followed. This resulted in the measurement of 12 out of the 16 most representative edaphic parameters across the 8 plant communities/associations (see Table 2). The statistical analysis reveals that the communities with a basic pH value above 7 correspond to *Anacyclo clavati-Hordeetum leporine* (AcH), *Bromo scoparii-Hordeetum leporinii* (BH), *Papaveri rhoeadis-Diplotaxietum virgatae* (PD), *Centaureo baeticae-Glebionetum discolori* (CbGd), and *Urtico urentis-Malvetum neglectae* (UM), these being the communities with the highest cation exchange capacity (CIC), which shows their eutrophic character, as opposed to the oligotrophic character of *Linario sparteae-Raphanetum raphanistri* (LR), *Trifolio cherleri-Taeniatheretum capitis-medusae* (TT), and *Trifolio cherleri-Plantaginetum bellardii* (TP), in which the CIC is lower.

The highest organic matter (OMM) and total nitrogen (TN) contents correspond to the communities dominated by *Malva neglecta* Wallar (UM), but the highest sand content corresponds to the communities dominated by *Plantago bellardii* All., *Taenitherum caput-medusae* (L.) Nevski, and *Raphanus raphanistrum* L., communities that develop on acid sandy soils.

In the edaphic analysis carried out 13 years later, comparing the 47 edaphic samples collected in 2018 with those from 2005, it is evident that there have been some changes in edaphic values. Notably, significant differences were observed in cation exchange capacity (CEC), with a Bonferroni-corrected *p*-value of 0.0003. In contrast, the remaining parameters showed *p*-values of less than 0.05 (see Figure 2).

Table 2. Edaphic values of edaphic parameters of 8 grassland-herbaceous associations. CEC = cation exchange capacity in meq/100 g; OOM = oxidable organic matter in %; Nt = total nitrogen in %; Pa = assimilable phosphorus in ppm; Mgc = exchangeable magnesium in meq/100 g; Kc = exchangeable potassium in meq/100 g; pF 15 atm = pressure at 15 atm (water retention capacity) in %; Tx arc = clayey texture in %; Tx ar = sandy texture in %; Tx lim = silty texture in %; EC = conductivity mmhos/cm; pH. 1AcH. *Anacyclo clavati-Hordeetum leporini* Cano-Ortiz et al. 2009. 2BH. *Bromo scoparii-Hordeetum leporinii* Rivas Martínez 1978. 3LR. *Linario sparteae-Raphanetum raphanistri* Cano-Ortiz et al. 2013. 4PD. *Papaveri rhoeadis-Diplotaxietum virgatae* Rivas Martínez 1978. 5CbGd. *Centaureo baeticae-Glebionetum discolori* Cano et al. 2024. 6UM. *Urtico urentis-Malvetum neglectae* (Knapp) Lohmeyer in Tüxen 1950. 7TT. *Trifolio cherleri-Taeniatheretum capitis-medusae* Rivas-Martínez and Izco 1977. 8TP. *Trifolio cherleri-Plantaginetum bellardii* Rivas Goday 1958.

	1AcH	**2BH**	**3LR**	**4PD**	**5CbGd**	**6UM**	**7TT**	**8TP**
CEC	**15.365**	**10.544**	**6.661**	**14.304**	**11.68**	**10.889**	**9.63**	**5.217**
OOM	**1.541**	**1.667**	**0.75**	**1.02**	**1.574**	**1.904**	**1.458**	**1.569**
Nt	**0.115**	**0.133**	**0.064**	**0.09**	**0.129**	**0.179**	**0.084**	**0.086**
Pa	**9.789**	**15.4**	**4.824**	**15.35**	**20.95**	**36.19**	**5.111**	**5.263**
Mgc	**1.683**	**1.068**	**0.835**	**2.351**	**2.716**	**1.698**	**1.097**	**0.519**
Kc	**0.79**	**0.375**	**0.259**	**1.002**	**1.476**	**1.266**	**0.156**	**0.142**
pF 15 atm	**15.322**	**8.203**	**7.366**	**19.117**	**14.24**	**13.197**	**6.673**	**4.791**
Tx arc	**17.758**	**14.503**	**17.28**	**40.015**	**24.24**	**21.293**	**13.59**	**9.682**
Tx ar	**20.448**	**54.254**	**64.238**	**19.986**	**37.85**	**46.001**	**64.93**	**75.470**
Tx lim	**61.794**	**31.245**	**18.51**	**40**	**37.94**	**32.712**	**21.49**	**14.869**
EC	**0.355**	**0.122**	**0.211**	**0.286**	**0.491**	**0.565**	**0.049**	**0.047**
pH	**8.275**	**7.475**	**6.616**	**8.085**	**7.943**	**7.776**	**6.13**	**6.047**

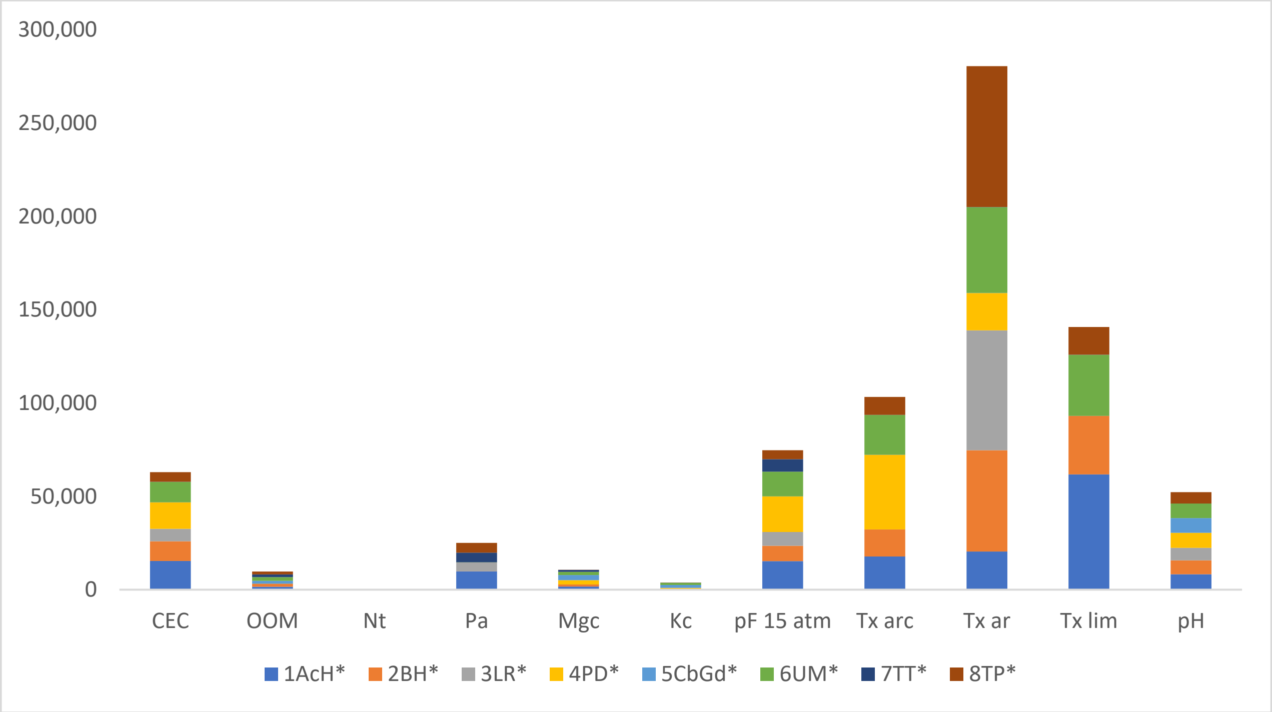

Figure 2. *Cont.*

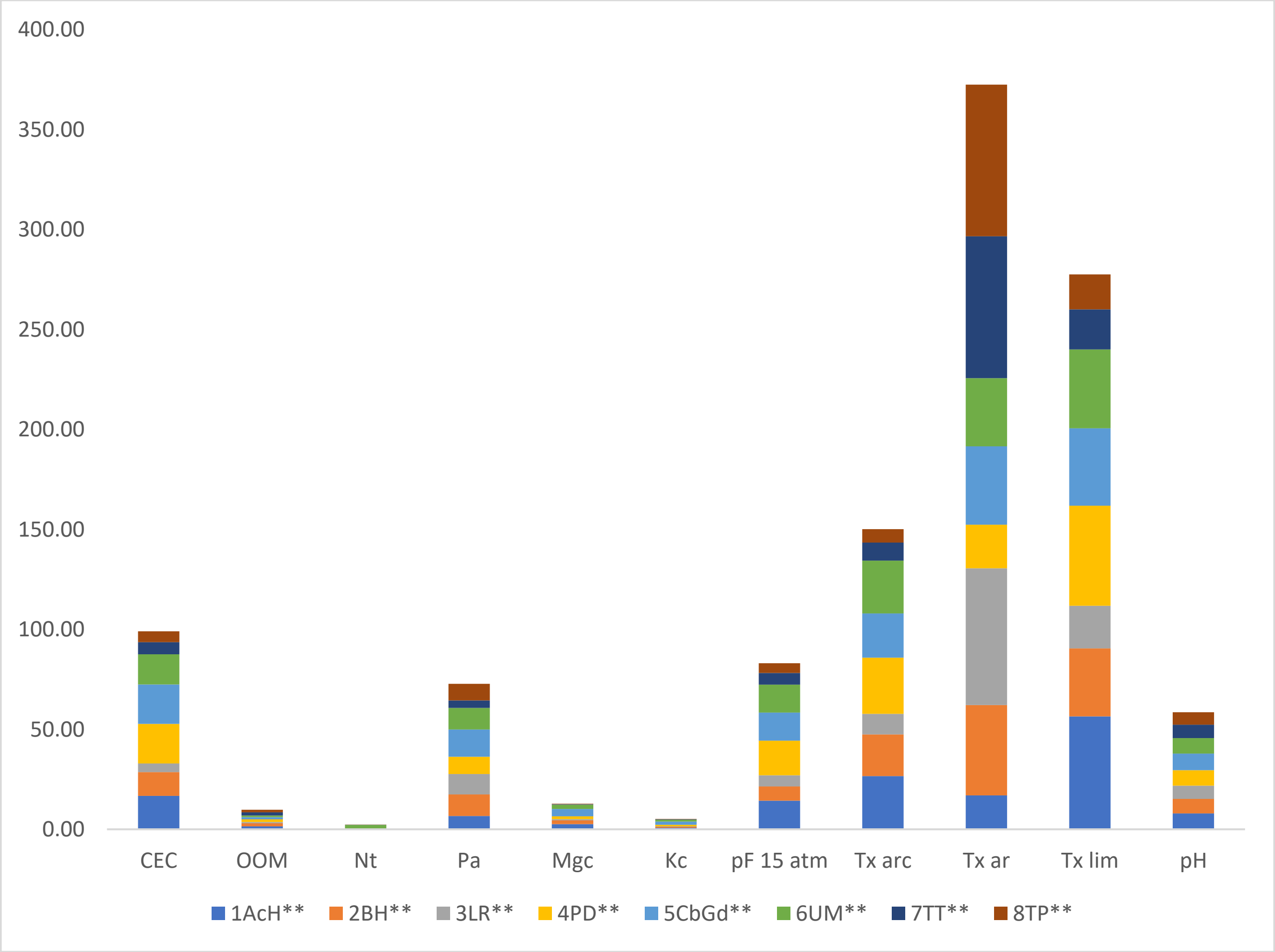

Figure 2. Comparative analysis of edaphic evolution for 8 associations between 2005 (*) and 2018 (**). 1AcH. *Anacyclo clavati-Hordeetum leporini* Cano-Ortiz et al. 2009. 2BH. *Bromo scoparii-Hordeetum leporinii* Rivas Martínez 1978. 3LR. *Linario sparteae-Raphanetum raphanistri* Cano-Ortiz et al. 2013. 4PD. *Papaveri rhoeadis-Diplotaxietum virgatae* Rivas Martínez 1978. 5CbGd. *Centaureo baeticae-Glebionetum discolori* Cano et al. 2024. 6UM. *Urtico urentis-Malvetum neglectae* (Knapp) Lohmeyer in Tüxen 1950. 7TT. *Trifolio cherleri-Taeniatheretum capitis-medusae* Rivas-Martínez and Izco 1977. 8TP. *Trifolio cherleri-Plantaginetum bellardii* Rivas Goday 1958. CEC = cation exchange capacity in meq/100 g; OOM = oxidable organic matter in %; Nt = total nitrogen in %; Pa = assimilable phosphorus in ppm; Mgc = exchangeable magnesium in meq/100 g; Kc = exchangeable potassium in meq/100 g; pF 15 atm = pressure at 15 atm (water retention capacity) in %; Tx arc = clayey texture in %; Tx ar = sandy texture in %; Tx lim = silty texture in %; pH.

3.1. Colocalization Network

In the study of various associations, we utilized the colocalization network to compare the association of *Anacyclo clavati-Hordeetum leporini* (AH) with *Bromo scoparii-Hordeetum leporini* (BH). This analysis revealed a set of common plants in both associations, including *Medicago polymorpha*, *Bromus diandrus*, *Bromus hordeaceus*, and *Hordeum leporinum*. As illustrated in Figure 3, the total number of species in both associations was divided into two distinct groups. This differentiation was primarily attributed to notable variations in edaphic parameters such as phosphorus (P), potassium (K), and pH, which influence the presence of these associations.

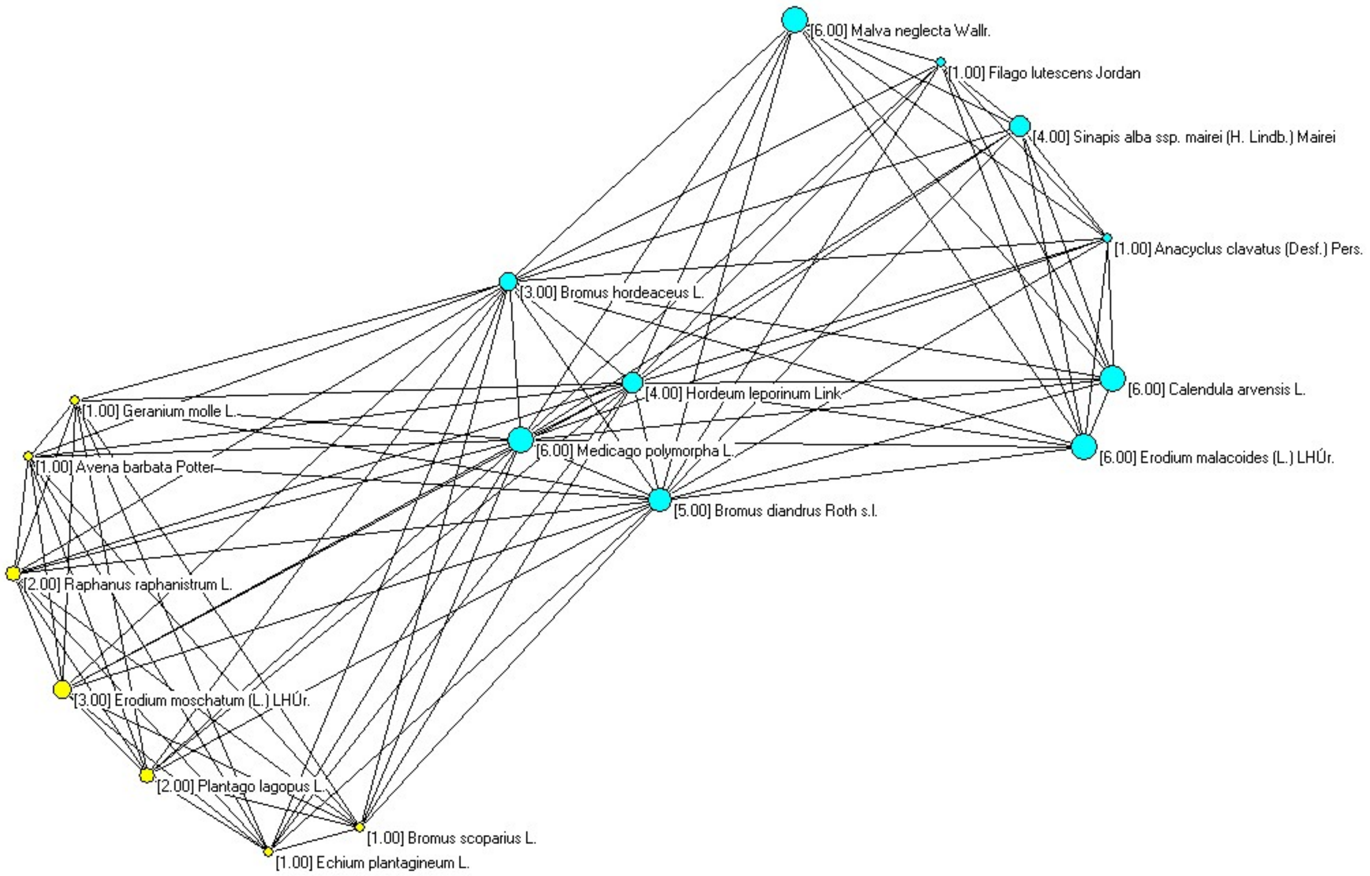

Figure 3. Phytosociological colocalization network of the associations of *Anacyclo clavati-Hordeetum leporini* (AH) and *Bromo scoparii-Hordeetum leporini* (BH); the species of the AH association are represented by turquoise blue nodes and those of the BH association by green nodes. The central white nodes represent the common species.

3.2. Bayesian Probabilistic Networks

We applied Bayesian probabilistic networks to two of the edaphic remote associations. In the case of *Filago lutescens*, prior evidence propagation shows that, in general, most of the edaphic parameters are wide-ranging and that this species can also be found with different Van der Maaler indexes. However, when prior evidence is established that the species is found with the highest abundance index (9 in this case), the propagation of the evidence results in a characteristic and narrow distribution for many of the soil attributes, which allows us to determine that this species is found in higher abundance in soils where the composition must be very specific (Figure 4).

For the *Urtico urentis-Malvetum neglactae* association, the *Malva neglecta* species is distributed as follows: 28.18% are not present, 10% have a Van deer Maaler index of 5, 5.45% have an index of 7, 23.64% have an index of 8, and 32.73% have an index of 9. For this distribution, we found that K values in 78.41% of the cases presented values lower than or equal to 1.535 meq/100g, P in 78.41% presented values lower than or equal to 63.750 p.p.m, M.O.O. in 87.50% presented values lower than or equal to 3.935%, and N in 92.05% of the cases presented values lower than or equal to 0.387%. When propagating the previous evidence that the species has the highest Van deer Maaler index, we observed how the percentage of the previous edaphic parameters for the mentioned values decreased, increasing its percentage of higher values (Figure 5).

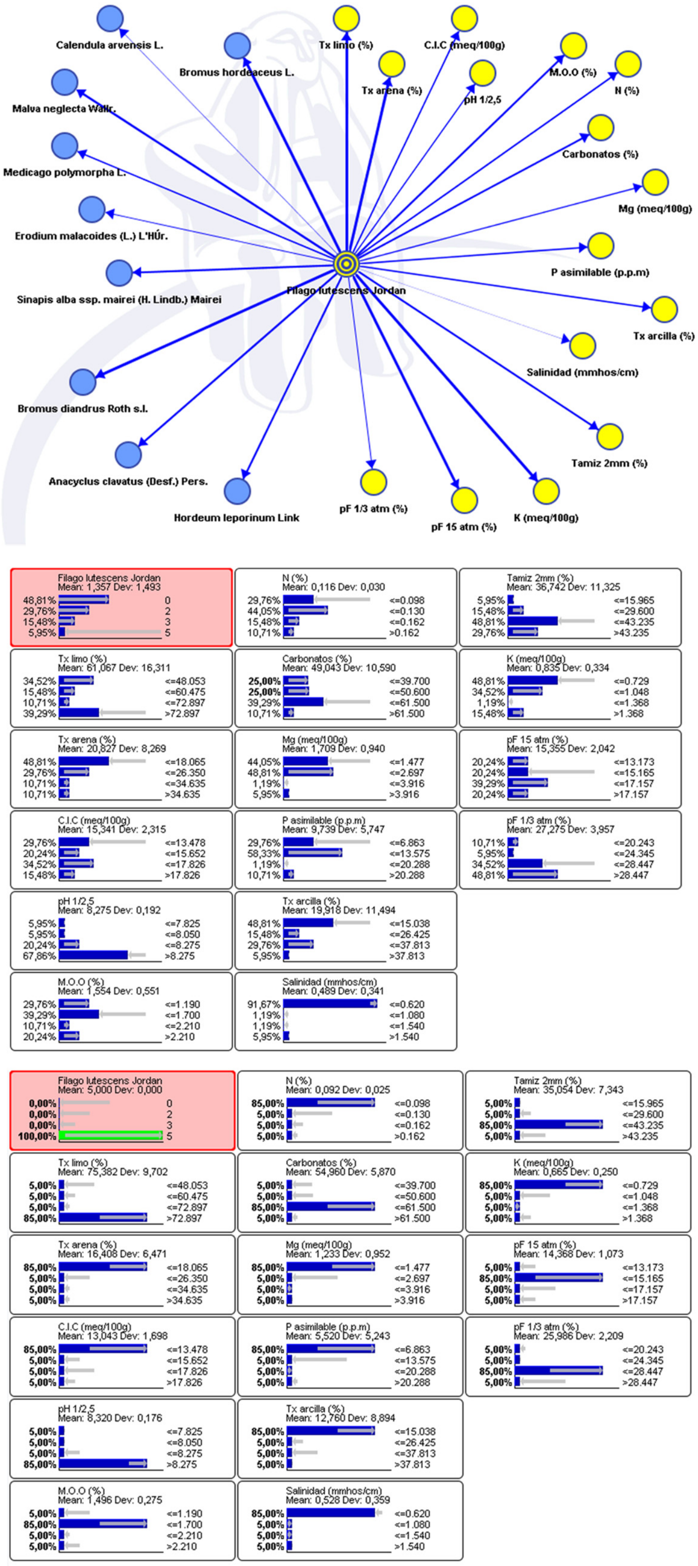

Figure 4. Bayesian network and propagation evidence for *Filago lutescens*, included in the *Anacyclo clavati-Hordeetum leporini* association.

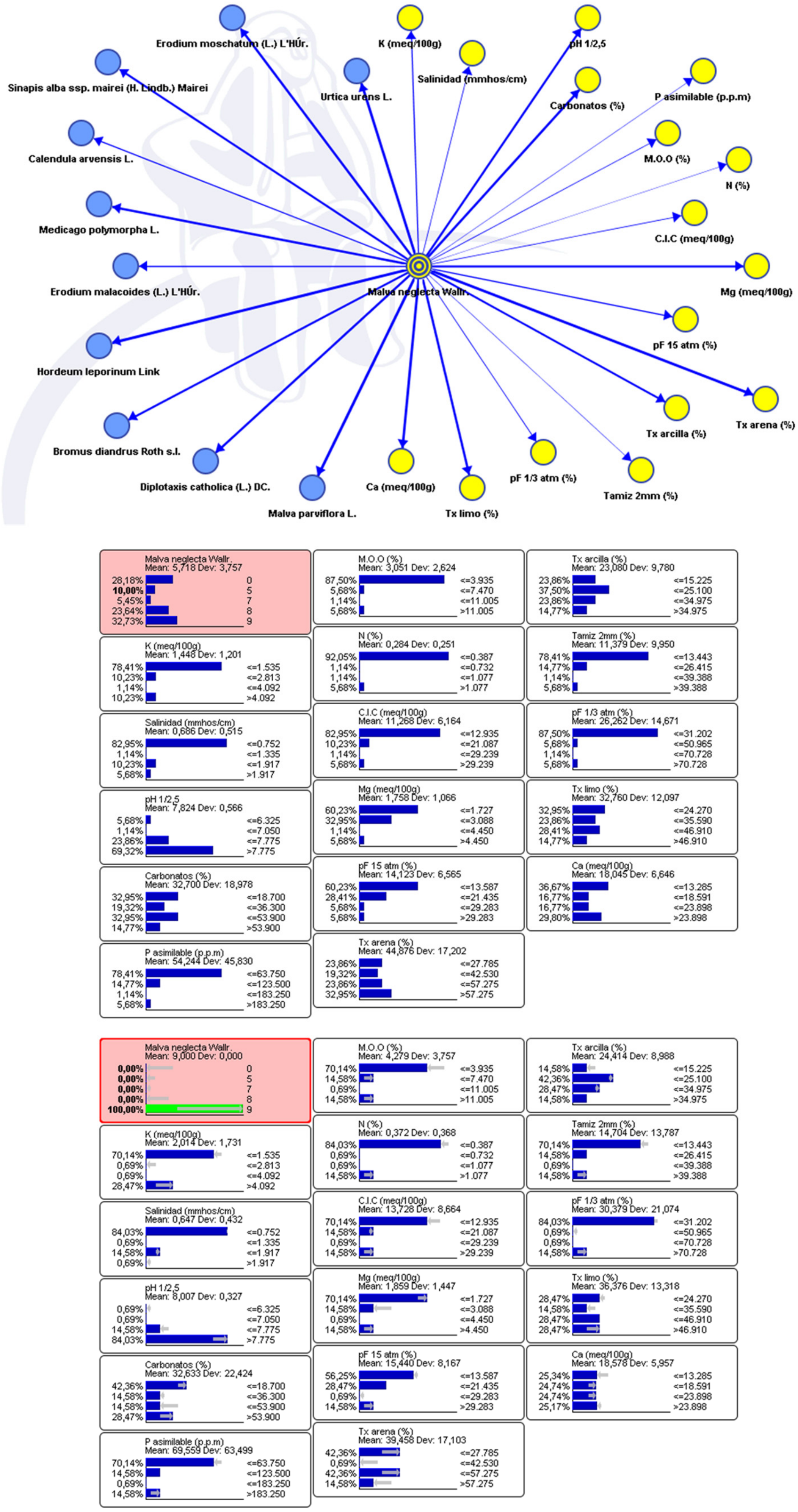

Figure 5. Bayesian network and propagation of the evidence for *Malva neglecta* in the *Urtico urentis-Malvetum neglactae* association.

3.3. Decision Trees

3.3.1. *Brassica barrelieri*

Out of the 16 general edaphic parameters, only 5 are involved in the classification of *Brassica barrelieri*: pH, salinity, pF 15 atm, Tx sand, K. This species reaches Van deer Maaler indices of 3 when salinity reaches values lower than or equal to 0.08 mmhos/cm, a pH higher than 6.2, Tx sand lower than or equal to 73.27% and K lower than or equal to 0.164 meq/100 g. (Table 3) (Figure 6).

Table 3. Attributes ordered by information gain for *Brassica barrelieri*.

Brassica barrelieri		
0.191	7	pH
0.129	15	Salinity
0.108	10	pF 15 atm
0.099	12	Tx_sand
0.092	8	K
0.000	4	Mg
0.000	5	MOO
0.000	1	CIC
0.000	3	P_assimilable
0.000	2	Carbonates
0.000	9	pF13 atm
0.000	11	Tx_clay
0.000	6	N
0.000	13	Tx_silt
0.000	14	Sieve 2 mm

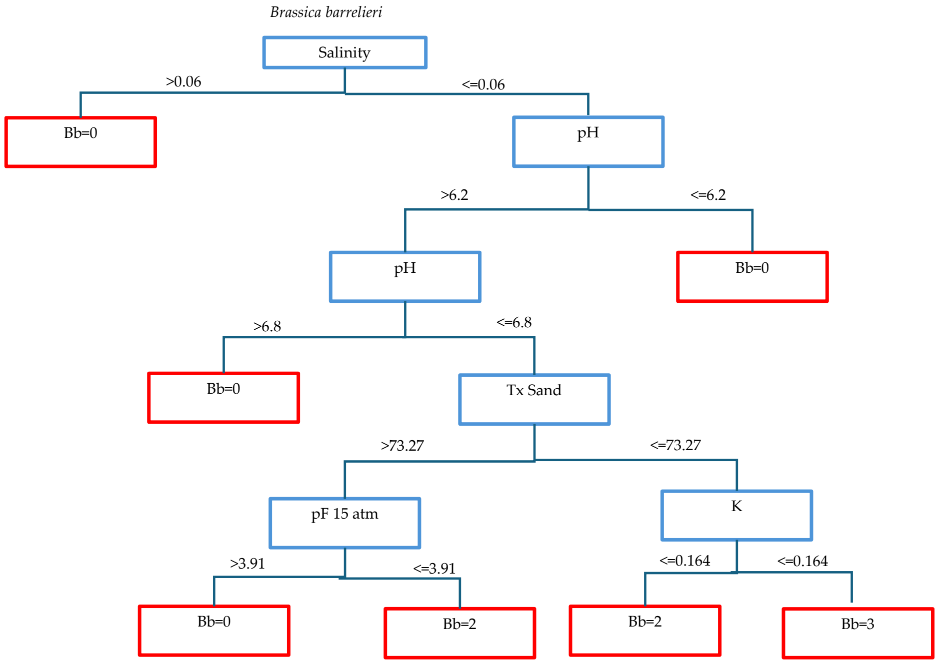

Figure 6. Decision tree for *Brassica barrelieri* species.

3.3.2. *Avena barbata* subsp *lusitanica*

As can be seen in Table 4, the classification of this species depends on soil parameters such as salinity, K, pH, MOO, P, Tx Sand, pF 1/3 atm, and pF 15 atm. The most influential parameter is salinity since it has the highest GI value (0.290). In the decision tree shown below for this species, we observed Van deer Maaler indices of 5 for salinity values less than or equal to 0.06 mmhos/cm, K values greater than 6.5 meq/100 g, and pH less than or equal to 6.5 (Table 4) (Figure 7).

Table 4. Attributes, ordered by the gain of information for the species.

Avena barbata* subsp. *lusitanica		
0.290	15	Salinity
0.249	7	pH
0.201	2	Carbonates
0.203	8	K
0.160	10	pF 15 atm
0.151	12	Tx_sand
0.118	9	pF13 atm
0.112	13	Tx_silt
0.094	11	Tx_clay
0.093	1	CIC
0.090	4	Mg
0.087	3	P_assimilable
0.084	5	MOO
0.000	6	N
0.000	14	Sieve 2 mm

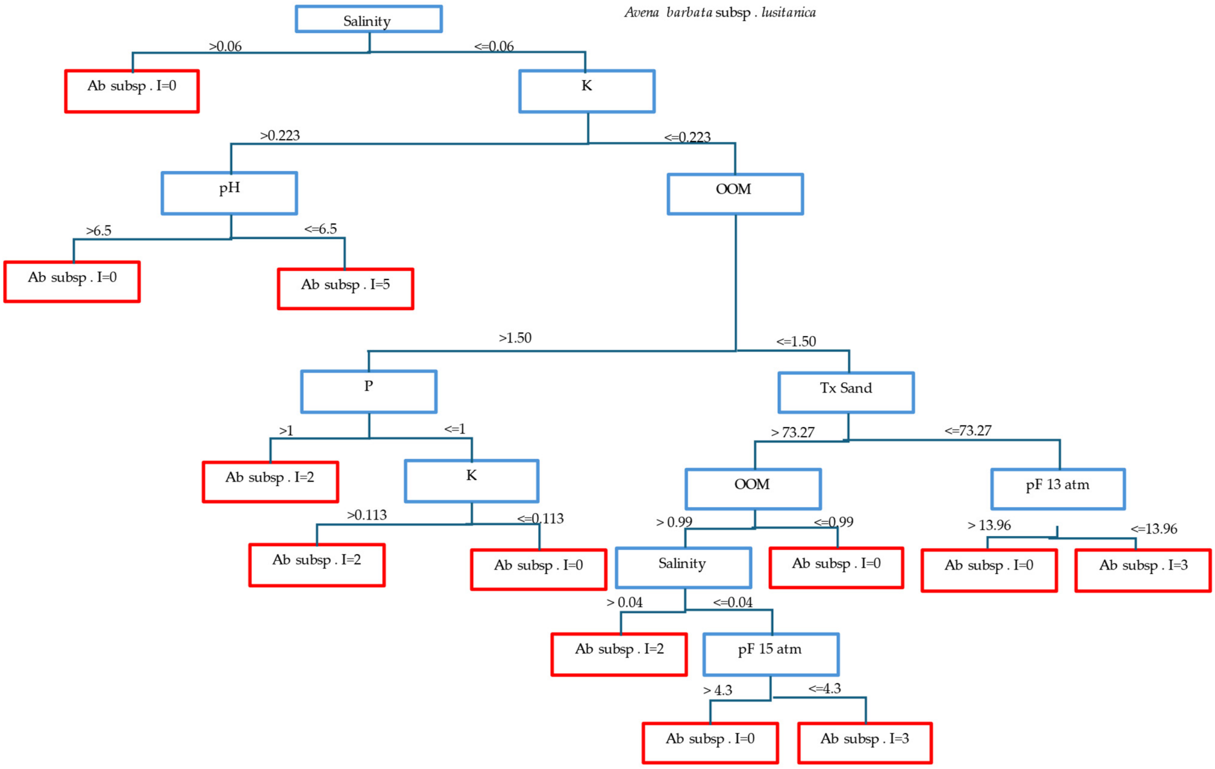

Figure 7. Decision tree for the species *Avena barbata* subsp. *lusitanica*.

3.4. Changes in the Value of the Phytosociological Importance Index (IVI)

The IVI serves as both a classifier and quantifier of a species' phytosociological importance within an association. For this reason, it has been used to measure the changes in the prominence of each species across different associations from 2005 to 2018.

Significant changes in the IVI of the associations from 2005 to 2018 were as follows.

AcH *Anacyclo clavati-Hordeetum leporini*

- Appearance: Anagallis arvensis, Centurea melitensis, Diplotaxis virgata (6.19), Eryngium campestre (15.14), Papaver rhoeas, Poa infirma, and Spergula arvensis.
- Disappearance: Bromus, Calendula arvensis, Erodium, Malva neglecta, and Sinapis alba.
- Significant increase in Plantago lagopus from 4.92 to 11.26, Diplotaxis catholica and Euphorbia serrata.
- Very significant decrease in Hordeum leporinum from 82 to 11.

BH *Bromo scoparii-Hordeetum leporini*

- Disappearance: Convolvulus arvensis and Cynara humilis.
- Significant increase in Vulpia geniculata (1.56 to 6.05), Raphanus raphanistum (2.78 to 9.75), Geranium molle (13.89 to 21.67), Euphorbia helioscopia (1.29 to 4.79), Calendula arvensis (2.2 to 7.83), and Avena sterilis (2.27 to 6.63).
- Decrease in Anacyclus calvatus, Hordeum leporini (79.78 to 31.58), and Malva.

PD *Papaveri rhoeadis-Diplotaxietum virgatae*

- Appearance: Galium parisiense (10.68), Melilotus sulcatus (5.07), Ranunculus arvensis (3.92), and Valantia muralis (10.87).
- Disappearance: Hordeum leporinum (3.73), Lamium amplexicaule (3.94), Lolium temulentum (4.6), Papaver rhoeas (4.02), Poa bulbosa (1.61), Sinapis alba (3.32), Silene, Sonchus oleraceus (4.85), and Stellaria media (5.42).
- Increase in Plantago lagopus (0.29 to 3.08) and Ononis biflora (0.31 to 5.39).
- Decrease in Medicago polymorpha (7.31 to 0.5), Diplotaxis catholica (56.24 to 6.42), Diplotaxis virgata (18.73 to 11.37), and Erodium melacoides (5.12 to 2.09).

LR *Linario spartei-Raphanetum raphanistrii*

- Appearance: Arenaria serpyllifolia (30.91), Chamaemelum fuscatum (10.63), Filago lutescens (1.81), and Tordylium maxinum (1.81).
- Disappearance: Hordeum leporinum (4.87), Lolium temulentum (4.88), Brassica barrelieri (2.13), Erodium botrys (2.97), Erodium malacoides (3.01), Erodium moschatum (3.93), Geranium rotundifolium (1.58), Linaria spartea (2.14), Malva neglecta (2.26), Malva parviflora (1.12), and Rumex anguiocarpus (3.11).
- Increase in Plantago lagopus (0.57 to 5.74), Anthemis arvensis (3.85 to 16.41), Cerastium glomeratum (0.52 to 14.83), Diplotaxis catholica (1.36 to 9.10), Scorpiurus verniculatus (0.94 to 6.61), and Stellaria media (0.17 to 3.76).
- Decrease in Medicago polymorpha (15.3 to 2.52), Raphanus raphanistrum (65.17 to 15.71), Calendula arvensis (4.46 to 1.58), Bromus diandrus (5.22 to 2.19), and Bromus rigidus (5.52 to 0.92).
- Unchanged Ornithopus compressus (1.86 to 1.9).

CbGd *Centaureo baeticae-Glebionetum discolori*

- Appearance: Arenaria serpyllifolia (4.95), Anchusa undulata (5.4), and Veronica cimbalaria (4.42).
- Disappearance: Hordeum leporinum (4.27), Lactuca serriola (4.14), and Rapistrum rugosum (3.24).
- Increase in Avena barbata (0.33 to 3.75), Calendula arvensis (4.65 to 10.18), Carduus pycnocephalus (2.02 to 4.69), Centaurea pullata subsp. baetica (1.47 to 4.82), Diplotaxis virgata (18.73 to 44.31), Ecballium elaterium (0.73 to 4.46), Erodium malacoides (7.38 to 4.56), Malva parviflora (3.63 to 10.47), and Onopordum nervosum (0.25 to 20.35).
- Decrease in Medicago polymorpha (4.2 to 0.66), Glebionis discolor (83.87 to 6.75), Bromus diandrus (8.53 to 4.11), and Avena sterilis (10.22 to 4.56).

UM *Urtico urentis-Malvetum neglectae*

- Appearance: Aira cupaniana (2.45), Anacyclus clavatus (4.82), Arenaria serpyllifolia (11.48), Campanula erinus (3.76), and Scorpiorus muricatus (4.90).
- Disappearance: Hordeum leporinum (6.91), Avena sterilis (3.16), and Urtica urens (8.37).
- Increase in Anthemis arvensis (0.22 to 9.5), Bromus rigidus (1.10 to 5.30), Calendula arvensis (7.45 to 10.9), Diplotaxix catholica (8.28 to 12.26), D. virgata (0.29 to 5.32), Galium aparine (2.35 to 4.87), and Sherardia arvensis (0.9 to 4.33).
- Decrease in Medicago polymorpha (6.53 to 3.97), Malva neglecta (45.98 to 4.88), M. parviflora (29.25 to 5.83), and Bromus diandrus (9.32 to 3.73).

TT *Trifolio cherleri-Taeniantheretum caput-medusae*

- Disappearance: *Filago gallica* (1.13) and *Ornithopus compressus* (4.24).
- Increase in *Trifolio cherleri* (10.24 to 20.91), *Trincia hispida* (7.88 to 14.88), *Vulpia membranace* (10.63 to 28.06), *Echium plantagineum* (4.7 to 23.58), and *Anacyclus clavatus* (1.08 to 4.68).
- Decrease in *Bromus hordeaceus* (30.21 to 4.68), *Bromus tectorium* (8.72 to 1.29), *Gaudinia fragilis* (0.27 to 4.31), *Plantago lagopus* (7.67 to 4.01), and *Taeniatherum caput-medusae* (30.91 to 25.60).

TP *Trifolio cherleri-Plantaginetum*

- Disappearance: *Erodium primulaceum* (2.81).
- Appearance: *Anthemis arvensis* (5.29).
- Increase in *Trifolio cherleri* (12.27 to 13.36), *Vulpia myuros* (4.11 to 8.33), *Echium plantagineum* (0.43 to 5.53), *Anacyclus clavatus* (0.8 to 8.70), *Brachypodium distachyum* (10.72 to 14.18), *Brassica barrelieri* (0.37 to 6.25), *Ornithopus compressus* (4.28 to 8.48), and *Taeniatherum caput-medusae* (2.01 to 13.8).
- Decrease in *Plantago bellardi* (42.35 to 12.08), *Xolantha guttata* (27.89 to 23.61), and *Hypochaeris achyrophorus* (12.19 to 2.58).

3.5. Biodiversity Analysis

This study examines changes in floristic composition between the 2005 and 2018 samples. Using the XLSTAT software 2024.3, different tests were applied to assess whether there had been a loss of floristic diversity. The analysis of the parametric normality test indicated that some variables did not meet the normality assumptions (see Table 5). Given the sufficient amount of data available, non-parametric or robust statistical tests were employed.

Table 5. Parametric normality test for the years 2005 and 2018.

Variable/Test	Shapiro–Wilk	Anderson–Darling	Lilliefors	Jarque–Bera
(Taxa_S ∣ 5)	0.0381	0.0055	0.001	0.393
(Taxa_S ∣ 18)	<0.0001	<0.0001	0.0001	<0.0001
(Individuals ∣ 5)	0.2202	0.2331	0.3205	0.3455
(Individuals ∣ 18)	0.0001	0.0003	0.0032	<0.0001
(Dominance_D ∣ 5)	<0.0001	<0.0001	<0.0001	<0.0001
(Dominance_D ∣ 18)	<0.0001	<0.0001	0.0001	0.0013
(Simpson_1-D ∣ 5)	<0.0001	<0.0001	<0.0001	<0.0001
(Simpson_1-D ∣ 18)	<0.0001	<0.0001	0.0001	0.0013
(Shannon_H ∣ 5)	0.009	0.0166	0.0281	0.0081
(Shannon_H ∣ 18)	0.1108	0.1895	0.3501	0.4779
(Evenness_eˆH/S ∣ 5)	0.0453	0.0598	0.0335	0.0656
(Evenness_eˆH/S ∣ 18)	0.0735	0.1157	0.0994	0.1871
(Equitability_J ∣ 5)	0.0059	0.0029	0.0144	0.0002
(Equitability_J ∣ 18)	0.0088	0.0041	0.0006	0.0508

3.6. Comparative Analysis of Biodiversity Indices

To determine whether there were differences between the different diversity indices calculated for each inventory, we compared the means and medians of the inventories from 2005 and 2018. This approach was necessary because our variables did not satisfy the assumptions of normality and homoscedasticity (see Table 6). The Kruskal–Wallis test (see Table 7) has been employed, with values below 0.0001 highlighted in bold to indicate non-compliance. The final column indicates whether significant differences exist between the diversity indices of the 2005 and 2018 inventories.

Table 6. Comparative analysis of means and medians 2005 and 2028.

Statistics	Nº Ob.	Minimum	Maximum	1st Quartile	Median	3rd Quartile	Mean	Variance (n − 1)	*S. desviation* (n − 1)
Taxa_S-18	100	1	13	3	4	6	4.48	6.47434343	2.54447312
Taxa_S-5	100	5	22	10	13	15	12.77	9.75600191	3.12345993
Individuals-18	100	2	47	10	15	21	16.64	98.2327273	9.91124247
Individuals-5	100	19	70	34	40	47	41	87.0392157	9.329481
Dominance-18	100	0.075	1	0.158	0.227	0.333	0.328	0.06855196	0.2618243
Dominance-5	100	0.044	0.257	0.07	0.081	0.102	0.089	0.00090685	0.03011403
Simpson-18	100	0	0.924	0.666	0.772	0.841	0.671	0.06855196	0.26182429
Simpson-5	100	0.742	0.955	0.897	0.918	0.929	0.91	0.00090694	0.0301155
Shannon-18	100	0	2.525	0.986	1.427	1.796	1.329	0.41862055	0.64700893
Shannon-5	100	1.516	3.126	2.342	2.562	2.715	2.522	0.07756315	0.27850162
Evenness-18	100	0.862	1.206	0.962	1.002	1.049	1.013	0.00481029	0.06935622
Evenness-5	100	0.908	1.123	0.9828	1.007	1.03	1.008	0.00151606	0.03893656
Equitability-18	100	0.844	1.18	0.9763	1.008	1.044	1.013	0.00381248	0.0617453
Equitability-5	100	0.942	1.051	0.9928	1.003	1.012	1.002	0.00026636	0.0163205

Table 7. Kruskal–Wallis test, where 5 tests are positive for differences in the diversity indices of the 2005 and 2018 inventories. * Are there differences between the diversity indices of the inventories between 2005 and 2018?

Variable\Test	K	Alpha	Kruskal–Wallis	Int Conf. Inf	Int conf. Sup	*
Taxa_S	167.1052	0.05	<0.0001	0	0	
Individuals	167.1052	0.05	<0.0001	0	0	Yes
Dominance_D	170.6088	0.5	<0.0001	0	0	Yes
Simpson_1-D	170.6096	0.05	<0.0001	0	0	Yes
Shannon_H	180.2061	0.05	<0.0001	0	0	Yes
Evenness^H/S	0.0076	0.05	0.9365	0.9302	0.9428	No
Equitability_J	2.4847	0.05	0.1125	0.1044	0.1206	No

The Conover–Iman test is a non-parametric test used to see if there are pairwise differences between the categories of a variable. In this case, we analyzed whether there were significant differences in the different biodiversity indices between the same associations sampled in 2005 and 2018. Those *p*-values of <0.0003 (corrected by the Bonferroni method) indicate that there are significant differences between the associations sampled in 2005 and 2018 for each diversity variable (see Table 8).

Table 8. The *p*-value corrected by Bonferroni's method = 0.0003. AcH: *Anacyclo clavati-Hordeetum leporini*. BH: *Bromo scoparii-Hordeetum leporinii*. LsRr: *Linario sparteae-Raphanetum raphanistri*. PD: *Papaveri rhoeadis-Diplotaxietum virgatae*. CbGd: *Centaureo baeticae-Glebionetum discolori*. UM: *Urtico urentis-Malvetum neglectae*. TT: *Trifolio cherleri-Taeniatheretum capitis-medusae*. TP: *Trifolio cherleri-Plantaginetum bellardii*.

	AcH	BH	LsRr	PD	CbGd	UM	TT	TP
Individuals	<0.0001	0.1778	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dominance	<0.0001	0.0148	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Simpson	<0.0001	0.0149	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Shannon	<0.0001	0.0024	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Evenness	0.26881	0.9885	0.92241	0.99395	0.61605	0.11326	0.62285	0.03223
Equitability	0.08883	0.839	0.54202	0.46521	0.36612	0.08203	0.20952	0.39041

In the comparative analysis (Table 6), the average value of the number of species per inventory (taxa) for the year 2005 was 12.77 plants/sample, and in 2018 it was 4.48 plants/sample, which translates into a reduction of 65%. Individuals represents the average number of plants per inventory, changing from 41 in 2005 to 16.5 in 2018. Following the Conover–Iman test, we observed significant changes in all associations except in BH *Bromo scoparii-*

Hordeetum leporini, which behaved as the same community in both years, not changing over the course of 13 years. The dominance parameter was used to evaluate the structure of the community, reflecting how the species were represented. A high value indicates that few species dominated, while a low value suggests a more even distribution of species. For 2005, the mean dominance value was 0.089, indicating a relatively even distribution of species. In contrast, the mean dominance value for 2018 was 0.328, suggesting significant changes in species distribution.

As a result of the Conover–Iman test, significant changes are observed in all the associations, except in BH *Bromo scoparii-Hordeetum leporini*, where the same species continued to dominate in 2018.

In the case of the Simpson index, which measures the degree of concentration when individuals are classified into types, the results indicate that plants were distributed more or less homogeneously across the different types. The mean values were 0.910 for 2005 and 0.671 for 2018. In the case of the Shannon index, the diversity of all the communities sampled in 2018 decreased by 52.69% compared to 2005, so there were significant differences. Regarding evenness, we can see that there is no difference between the 2005 data and the 2018 data; the species are distributed in the same way, as the values are close to 1, far from 0, and consequently, in this case, no significant changes are observed. In the case of equitability, defined as the abundance of the dominant species with values close to 1, there were no significant differences either.

Using the Conover–Iman test, no significant changes were observed in any of the 8 associations sampled, as well as for the evenness test, since they measure similar things.

From the data obtained, it can be concluded that there has been a substantial decline in both the number of taxa and of individuals per sample, there are quantified changes in the floristic composition and how they are distributed in the associations, due to the fact that the characteristic plants that were present in 2005 are no longer present, and either they have been replaced by other generalist plants or some of the generalist plants have become dominant.

4. Discussion

The correlation between soil nutrient content and the abundance of the dominant species is relevant. Bayesian analysis highlighted the soil requirements of *Filago lutescens*, and the preference for nutrient-rich soils of *Malva neglecta*. In the case of the UM association in the Bayesian analysis, increasing the abundance of the dominant species *Malva neglecta* to 9 leads to higher values for the various soil parameters, especially MOO and nitrogen.

In the decision tree analysis, the factor with the greatest influence for *Brassica barrelieri*, with an information gain (GI) of 0.191, was pH. In contrast, for *Avena barbata* subsp. *lusitanica*, with a GI = 0.290, the triggering factor was salinity.

In the 13-year interval study, the floristic composition of most of the grassland communities sampled in 2005 by Cano-Ortiz changed, which was primarily due to alterations in cultivation techniques and, especially, an increased use of herbicides [64] since, at the soil level, there was only a change in the CEC parameter.

In the subsequent study conducted in 2018, using the same experimental plots, we demonstrated the floristic modification of plant communities, with a decrease in the abundance of the species and even the disappearance of some species, affecting biodiversity. This change was attributed to the increased use of herbicides over a 13-year period (Table 9) to control herbaceous species. Paradoxically, this led to a decrease in the characteristic community species and an increase in more generalist species, which are more resistant to herbicides.

Consequently, the ability of the species to diagnose the nutrient status of the soil is undeniable. However, there is no application of this ability in agricultural management, which is due to the lack of knowledge on the part of managers, as the subject is not taught in the curricula of universities, despite the continuous calls for attention to be paid to this field of study from institutions on sustainable development.

Table 9. Increase in herbicide sales between 2010 and 2019 in millions of euros (EUR) for the territories where the experimental plots are located.

YEAR	2010	2011	2012	2013	2014
Sales in EUR	5,782,080	5,577,310	5,500,910	8,513,880	8,122,990
YEAR	2015	2016	2017	2018	2019
Sales in EUR	9,393,560	12,882,900	12,882,250	15,857,150	14,441,070

Modern herbicides make important contributions to global food production by easily eliminating weeds and replacing destructive soil cultivation practices. However, the persistent application of herbicides to large numbers of weeds over vast areas can lead to the rapid evolution of herbicide resistance. Herbicides target specific enzymes and select mutations that confer resistance-conferring amino acid substitutions, which decrease herbicide binding [65].

Yet, due to the excessive use of herbicides, resistance to herbicides develops, which can be of two types: (1) multiple, when the plant develops a single resistance mechanism to several herbicides with different types of action; (2) cross-resistance, when the plant develops a single resistance mechanism to several herbicides with different types of action [64,66–68].

The most herbicide-resistant species in the studied area are *Conyza canadensis* and *Lolium rigidum*. Actually, these are considered the most herbicide-resistant generalist species. Crops prone to resistance generation are all those crops for which herbicides are used in a significant and repeated manner. The agronomic factors that foster the risk of resistance development in a particular field are listed in Table 10.

Table 10. Factors involved in herbicide resistance.

Factors	Low Risk	High Risk
Alternating sowing dates	Autumn and spring sowing	Autumn sowing only or spring sowing only
Crop alternation	More than three different crops	Monoculture
Weed infestation density	Low	High
Tillage system	Annual cultivation	No continuous tillage
Type of technique	Mechanical only	Herbicide only
Types of herbicides applied in the rotation	With different modes of action	With one mode of action
Efficacy obtained with herbicides in the last 3 years	Good	Poor
Presence of resistance in the area	No	Yes

Herbicide resistance is expressed in the floristic changes suffered by the vegetation between 2005 and 2018 in terms of the value of the phytosociological importance index.

The *Anacyclo clavati-Hordeetum leporini* association, developed on basic substrates, has undergone a profound transformation as a result of the significant decline of *Hordeum leporinum*, a characteristic species of the association and of the *Hordeion leporini* alliance. Despite being a generalist, edaphic species indifferent to soil conditions, it has been highly affected. The disappearance of *Malva neglecta*, also a species with a certain generalist character but with greater edaphic requirements and a greater need for oxidizable organic matter (OOM), the appearance of *Diplotaxis virgata*, *Papaver rhoeas*, suggests that the cultivation techniques that have most influenced the transformation of the association have been the loss of organic matter and the increase in tillage. The tendency is for the *Anacyclo clavati-Hordeetum leporini* association to be replaced by *Papaveri rhoeadis-Diplotaxietum virgatae*.

The *Bromo scoparii-Hordeetum leporini* association, which developed on siliceous substrates, has experienced less transformation than the previous association. This is largely due to the significant decrease in *Hordeum leporinum*, a characteristic species of both the association and the *Hordeion leporini* alliance. Despite being a generalist, edaphic indifferent species, its abundance has decreased by more than 50%. Additionally, *Cynara humilis*, a species that thrives in undisturbed, siliceous substrates, has completely disappeared. The significant increase in *Raphanus raphanistrum* suggests that the cultivation techniques that have most influenced the transformation of the association have been the loss of organic matter and the increase in tillage, enriching the soil with sand. This tendency indicates that this association is being gradually replaced by *Linario spartei-Raphanetum raphanistri*.

The sharp decrease in *Diplotaxis* species in the plots dominated by *D. virgata* and *D. catholica*, alongside the rise in generalist plants, suggests the implementation of inappropriate cultivation techniques. Moreover, the emergence of floristic elements with early phenology such as *Galim parisiense* and *Ranunculus arvensis*, which avoid herbicide impact because their phenologies do not coincide with the dates of application, leads us to conclude that the use of chemical products is driving the transformation of this association.

The pronounced drop in the species that are typical of the association of *Raphanus raphanistrum, Brassica barrelieri*, and *Linaria spartea*, coupled with the appearance of widely distributed species that are less sensitive to environmental conditions—*Plantago lagopus*, *Anthemis arvensis*, *Diplotaxis catholica*, and *Arenaria serpyllifolia*—allows us to state that the association has been transformed. This plant community, which thrives in silty-sandy substrates that are poor in carbonates and with a near-neutral pH on chromic cambisol-type soils, has been fragmented due to excessive soil compaction and herbicide use.

The *Centaureo baeticae-Glebionetum discolori* association has certain edaphic requirements, such as the quantity of MOO, the low decrease in *Glebionis discolor* from 83.87 to 6.75, the disappearance of *Hordeum leporinum,* and the strong increase in *Onopordum nervosum* from 0.25 to 20.35, may be a consequence of using selective herbicides and the increase in MOO, although this seems to be due to soil maturity (soils rich in organic matter and well-aged).

The tendency of the *Malva* communities, in terms of species appearance, disappearance, increase, and decrease, is being replaced by communities of the *Papaveri rhoeadis-Diplotaxietum virgatae* association, taking into consideration the plowing of the sample plots and a loss of nitrogen, both organic and inorganic.

The *Trifolio cherleri-Taeniatherum capiti-medusae* association is classified as a subnitrophilic grassland. Although the dominant species, *Taeniatherum caput-medusae*, has suffered a slight decrease, no significant transformation was observed. The species that have disappeared are not crucial to this association. However, the reduction in *Bromus hordeaceus* is notable, as it suggests a minor decrease in the MOO.

In the *Trifolio cherleri-Plantaginetum bellardii* association, there is a trend toward subnitrophic *Trifolio cherleri-Taeniatheretum capiti-medusae* grassland as the abundance of *Plantago bellardii* and *Xolantha guttata* decreased and *Taeniatherum caput-medusae* increased.

In the latter two associations, no anthropogenic influence was observed; still, there was at least a slight impact from livestock pressure.

Overall, with the exception of the *Plantago bellardi* communities, which are characterized by their low biomass, there is significant interest in promoting these areas as CO_2 sinks. These communities are also valuable for livestock and, fundamentally, for food security without relying on pollutants. Therefore, they perfectly fulfill several purposes: they act as bioindicators of nutrients and as carbon sinks while providing ecosystem services of high cultural, economic, and social value [69].

5. Conclusions

Current knowledge on soil bioindicators supports the introduction of comprehensive sustainable management in agriculture. To fully leverage this potential, it is imperative to equip universities and research centers with advanced technologies and offer training in these new methodologies. The widely used phytosociological method for studying vegetation enables the application of certain statistical approaches, such as collocation networks, probabilistic Bayesian networks, and decision trees. These methods reveal a strong correlation between the abundance index of the dominant species in a plant association and the soil's nutritional state. Effective application in agricultural management necessitates a thorough understanding of sampling techniques of the grasses present in the crop.

It is important to emphasize that continued reliance on chemical agents to control the spread of grasses and eliminate plant cover undermines the feasibility of a sustainable development model. This practice leads to water and soil degradation, food contamination, and economic losses due to the diminished value of grassland as an essential ecosystem service.

Generally speaking, agricultural practices worldwide often have a detrimental impact on the natural environment, driven by the global demand for food. This has led to the proliferation of agricultural companies and chemical suppliers, while rural communities have lacked adequate training in managing chemical pollutants. Additionally, universities and research centers have not sufficiently focused on edaphic bioindicators. Currently, there is a growing demand for sustainable development, which can only be achieved through a profound knowledge of resources and their rational use. Therefore, it is vital to train future managers in this sustainable development model.

For high-quality training in agriculture, ongoing research is also essential in various botanical-ecological and edaphic aspects. This research should focus on establishing correlations that enhance our understanding of the ecological niches of different species.

All in all, agricultural planning must prioritize respect for the environment and the optimization of each crop's ecological conditions. By acknowledging that every crop has its specific ecological optimum, we can reduce our environmental impacts. This approach would lead to the development of customized, non-standardized agricultural models, allowing us to either maintain certain crops or replace them with more productive and less polluting alternatives where applicable.

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