Bachelor thesis

Are the Ellenberg indicator values suitable for characterizing soils of Sicilian plantations?

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Abstract

Ellenberg indicator values (EIV's) are a tool for making inferences about the environment based on vegetation. Established in ecological sciences, their application in agricultural fields is not yet so common. This work investigates whether EIV's can help characterize soils in plantations with undergrowth in Sicily (Italy). For this purpose, vegetation relevés on five sites with three plots each were correlated with water content, pH and nitrate concentration. This revealed that moisture EIV correlated best with water content. Further correlations must be classified as difficult due to a paucity of data. An application of the EIV's on Sicilian plantations can be considered possible, but whether the application can be recommended cannot be clearly determined with the results of this work.

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1 INTRODUCTION

As a result of climate change, increasing extreme weather events and erosion, fertile soil and the storage of carbon in the soil are becoming increasingly important (FAO & ITPS, 2015). Due to this, humus, as the totality of dead organic matter in the soil (Amelung et al., 2018), and the increase of humus in the soil, is central in various discussions and research projects (4 per 1000, 2023; Giacche Verdi Bronte, 2022; Wöllecke & Linnemann, 2021). However, the implementation of humus-amplifying agriculture requires an analysis of the soil in the first place to determine its condition (Näser, 2021). This should be as simple and inexpensive as possible so that it can be widely applied. Therefore, an analysis of the vegetation could be suitable to draw conclusions about the properties of the soil.

A simple assessment of site factors with the help of vegetation in ecology is provided by the Ellenberg indicator values (EIV's, (Ellenberg, 1974; Ellenberg & Leuschner, 2010; Ellenberg et al., 2001). The EIV's are subdivided into seven sub-values associated with each species: Light (L), Temperature (T), Continentality (K), Reaction (R), Nitrogen (N), Salinity (S), and Moisture (F, German: "Feuchte"). The values are ordinally scaled, expressed by digits, and range from one to nine (L, T, K, R, N), or one to twelve (F), or 0-3 (S).

EIV's work by the presence and absence of species under the influence of various ecological factors. It is important to note in this context that the EIV's represent the ecological behavior under competitive conditions, not the physiological optimum of a plant (Ellenberg et al., 2001). Moreover, the EIV's represent conditions over an extended period of time (Schaffers & Sýkora, 2000).

Originally designed for the Central European flora, since then the EIV's have been extended to the Mediterranean region - more precisely, to the South Aegean (Böhling et al., 2002) and Italy (Guarino et al., 2012; Pignatti et al., 2005). To enable comparability between different site conditions, the L and T scales were expanded to twelve. Besides that, nothing else were changed in the system.

Due to their low financial cost and simplicity, EIV's could also be interesting for agriculture, especially in cropping systems with undergrowth. However, it is questionable how accurately the EIV's describe the site factors because their classification is based only on expert knowledge (Ellenberg, 1974; Ellenberg & Leuschner, 2010; Ellenberg et al., 2001). While the reliability of EIV's has already been tested for the Central European region (Schaffers & Sýkora, 2000; Wamelink et al., 2002), there is still a lack of examination of the EIV's in other regions, for example the Italian regions. Schaffers and Sykora (2000) used data from the Netherlands to correlate EIV's with various chemical, physical, and biological soil and vegetation values. Wamelink et al. (2002) also worked with data from the Netherlands and developed regression analyses between moisture EIV - mean spring groundwater level (MSL) and reaction EIV - pH (and further examined these for correlations with the phytosociological class of the plants). In Sicily the EIV's have been compared only with annual mean temperature as well as annual precipitation (Marcenò & Guarino, 2015) yet.

Based on the previous work and in order to address the lack of knowledge, the guiding question of this paper was developed: *Are the Ellenberg indicator values suitable for characterizing soils of Sicilian plantations?* Therefore, this paper is focused on quantifying the edaphic indicator values (1) reaction, (2) moisture and (3) nitrogen in an agroecosystem based on olive (*Olea europaea* L.), almond (*Prunus dulcis* (Mill.) D. A. Webb) and mixed fruit (*Prunus dulcis* (Mill.) D. A. Webb, *Prunus persica* (L.) Batsch as well as *Pistazia vera* L.) with soil chemical values and tried to find out if an application in agricultural field is possible.

2 MATERIAL UND METHODS

2.1 DESCRIPTION OF THE SITES

Four fields were studied in the locality of Bronte in eastern Sicily (Italy): (1) Placatorre of the organization Giacche Verdi Bronte (GV), (2) a directly adjacent field of the farmer M. Russo (MR), and (3,4) two fields close to each other of the farmer G. Rizzo (GRa and GRb, Figure 1). In each of the fields of GV, MR and GRa there is one study site (GV, MR, GR2,Figure 21, Figure 22), only in the field of GRb are located two Sites (GR1 and GR3,Figure 22). GV and MR are located at approximately lat 37°76' N and long 14°78' E southwest of Bronte on a loop of the Simeto River. GRa and GRb are located at lat 37°78' N and long 14°80' E (Geoportale Nazionale, 2014).

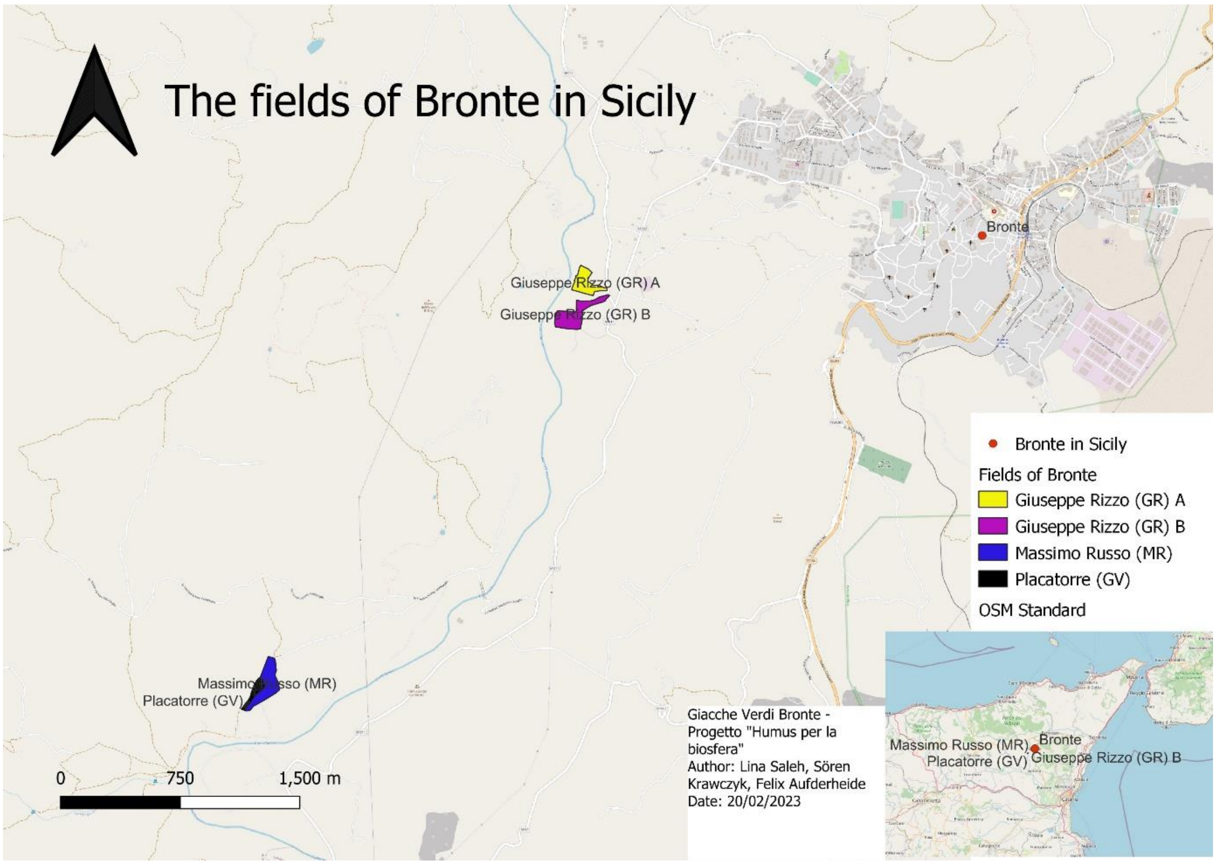

Figure 1: The fields of Giuseppe Rizzo (GRa and GRb), Massimo Russo (MR) and Placatorre (GV) in the surroundings of Bronte

GV and MR are located on landslide deposits of Holocene age and characterized as a geologically young site. The material is heterogeneous and partly strongly eroded. GRa and GRb are located in the sphere of influence of the vulcano Etna and therefore lie proportionally on volcanic parent rock on the one hand and on recent, alluvial deposits of the adjacent Simeto River on the other. The alluvial deposits consist mainly of gravel occurrence in a sandy-loamy matrix with a thickness up to 10 meters. These deposits also date from the Holocene period and thus are characterized young in geological terms. The rocks of volcanic origin consist of lava streams and pyroclastics with slag and lapilli dating from 15 000 - 3 900 years before Christ, which does not allow us to assign them clearly to the Holocene or Pleistocene. The lava mostly consists of slag flows with 'a'ā or block morphology. More rarely, it is pāhoehoe morphology. Mineral constituents are hawaiite, mugearite, but also plagioclase, pyroxene and olivine, which are present in varying proportions. The morphology of the lava flows is often already strongly degraded and difficult to recognize in detail (Arnone et al., 2012).

The study sites GR1, GR2 and GR3 are flat. In contrast, the study sites GV and MR are exposed to the south/southeast (MR) and west/southwest (MR), respectively. The inclination varies between 6-10% for MR and 1-2% for GV. The study site GV is characterized by terraces.

The soil types of the studied sites are very similar. Brown earths leached brown earths or regosols are to be expected in each case (Ballatore G.P. & Fierotti G., 1967).

The climate in Bronte can be described as Mediterranean. The mean annual temperature in the GV and MR fields is 16-17°C, and 15-16°C in the GR fields (Drago et al., 2012b). There is about 500-600 L/m² of precipitation per year in all fields (Drago et al., 2012a), and the town of Bronte has a precipitation median of 548 L/m²/year (REGIONE SICILIANA).

The vegetation of all fields is agricultural. The dominant cultivated species are olive (*Olea europaea* L.; GV and GR1, Figure 18Figure 20), almond (*Prunus dulcis* (Mill.) D. A. Webb; MR), and mixed fruit (*Prunus dulcis* (Mill.) D. A. Webb, *Prunus persica* (L.) Batsch, *Pistazia vera* L.; GR2, Figure 19). Study site GR3 is used primarily by grazing, and there are individual olive trees there (Figure 20). Except for MR, the other sites are also grazed, GV once a year.

2.2 METHODS

2.2.1 Vegetation

In each field, vegetation relevés were conducted from December 2022 to March 2023 using the Zurich-Montpellier method (Braun-Blanquet, 1964) The sampling areas for the vegetation relevés were randomly selected, but care was taken to ensure that a minimum distance of five meters was maintained, that there were no particular disturbances, and that there was enough space for the vegetation relevé. Three vegetation surveys of 1 m² each were conducted at each site (Figure 21, Figure 22), so that a total of 15 vegetation relevés were made. The area size was chosen considering the existing terrace structure of GV, where a bigger size of the relevés would have collided with the hillside of the terraces.

Weighted and unweighted mean values of EIV's for reaction, moisture, and nitrogen were calculated for the respective sites from the vegetation relevés. For the calculations the average Italian EIV's were used (Tichý et al., 2023). Although calculating with mean values provides mathematical problems due to the ordinal data structure, it has been established (Braak & Looman, 1986; Jongman et al., 2007; Schaffers & Sýkora, 2000). For further calculations, the weighted averages were used, which can be considered as an effective calibration form (Braak & Looman, 1986; Jongman et al., 2007; Schaffers & Sýkora, 2000).

2.2.2 Soil

Soil samples were collected from a depth of 0-10 cm, at the same locations as the vegetation relevés (Figure 21, Figure 22). Each study site was sampled twice, one in summer (June/July 2022), one in winter (November/December 2022), except for GR2 due to wetness in winter. A further sampling took place in July 2023, from this sampling the substrates for the quantification of soil types and nitrate were extracted.

The three samples each study site was subsequently analyzed as composite samples with H_2O in the laboratory for the pH measurement, both for the sampling in summer and for the sampling in winter, resulting in four values per study site, which were summed to give a mean value. Since no measurements could be taken at GR2 in winter, only two values are available for GR2. For the mean values, the pH values were first de-logarithmized to H^+ ion concentrations, which were then used to calculate the mean values and converted back to a pH value.

For the water content samples, only those taken in summer were considered due to wetness in winter and the associated lower informative value. The samples were dried at 105°C and the weight was measured before and after drying. The difference of the sample weight before and after drying gives the gravimetric water content of the sample. In addition to the samples designated for water content, storage samples were also considered. This results in two values per plot and six per study site.

For nitrate measurement, there was one composite sample per study site. The measurement of nitrate concentration was carried out according to accredited method UNI EN 12457-2:2004 + APAT CNR IRSA 4020 Man 29 2003 (APAT, 2003).

For the measurement of soil type proportions, as for nitrate, there was one composite sample per study site. The proportions of soil types were analyzed according to DM 13/09/1999 SO n 185 GU n 248 21/10/1999 (DM 13/09/1999 SO n 185 GU n 248 21/10/1999, 1999) and classified using the Bodenkundliche Kartieranleitung (Sponagel, 2005) as follows.

2.2.3 Statistical analysis

Microsoft Excel version 2307 (Microsoft Corporation, 2023) and R Studio version 4.0.5 (R Core Team, 2021) were used for statistical analysis. For the analysis with R Studio, the packages "car" (Fox & Weisberg, 2019), "ggplot2" (Wickham, 2016), "reshape2" (Wickham, 2007), "lmtest" (Zeileis & Hothorn, 2002), "stargazer" (Hlavac, 2022), "apaTables" (Stanley, 2021), and "corrplot" (Wei T., 2021) were further used.

The average values per site were used for the calculations. The available data were first tested for normal distribution using the Shapiro-Wilk test (Shapiro & Wilk M. B., 1965). Linear models (lm) of the EIV's were then constructed using the soil data (Chambers & Hastie, 1992). Here, the moisture EIV was related to water content (%) and the reaction EIV was related to pH. The nitrogen EIV is associated with nitrate concentration because nitrate is usually the most abundant plant-available nitrogen compound due to the rapid conversion of ammonium to nitrate (Norton, 2008). The linear models were tested for normality using the Shapiro-Wilk test (Royston, 1995) and for homoscedasticity using the studentized Breusch-Pagan test (Breusch & Pagan, 1979).

Furthermore, single factorial analyses of variance (Hastie, 2017) were performed to detect differences between sites. In the case of a significant single factorial analysis of variance, it was proceeded with paired t-tests with pooled standard deviation. The method chosen to adjust the p-value is Holm (Holm, 1979).

A result was considered significant at a p-value < 0.05, very significant at a p-value < 0.01, and highly significant at a p-value < 0.001 (Sachs, 2004).

3 Results

3.1 Differences between the sites

3.1.1 Differences based on soil analysis

3.1.1.1 Soil type

Soil type values are derived from a single measurement without replicates, which precluded ANOVA from analyzing differences between study sites. Nevertheless, it is visible that MR differs from the other sites mainly in terms of sand and clay but also in silt content (Figure 2).

For the study sites GR1, GR2 as well as GV the soil type was strongly sandy clay (Ts4), for the site GR3 sandy clay (Ts3) and for the site MR weak sandy clay (Ts2), simplified visible in Figure 3.

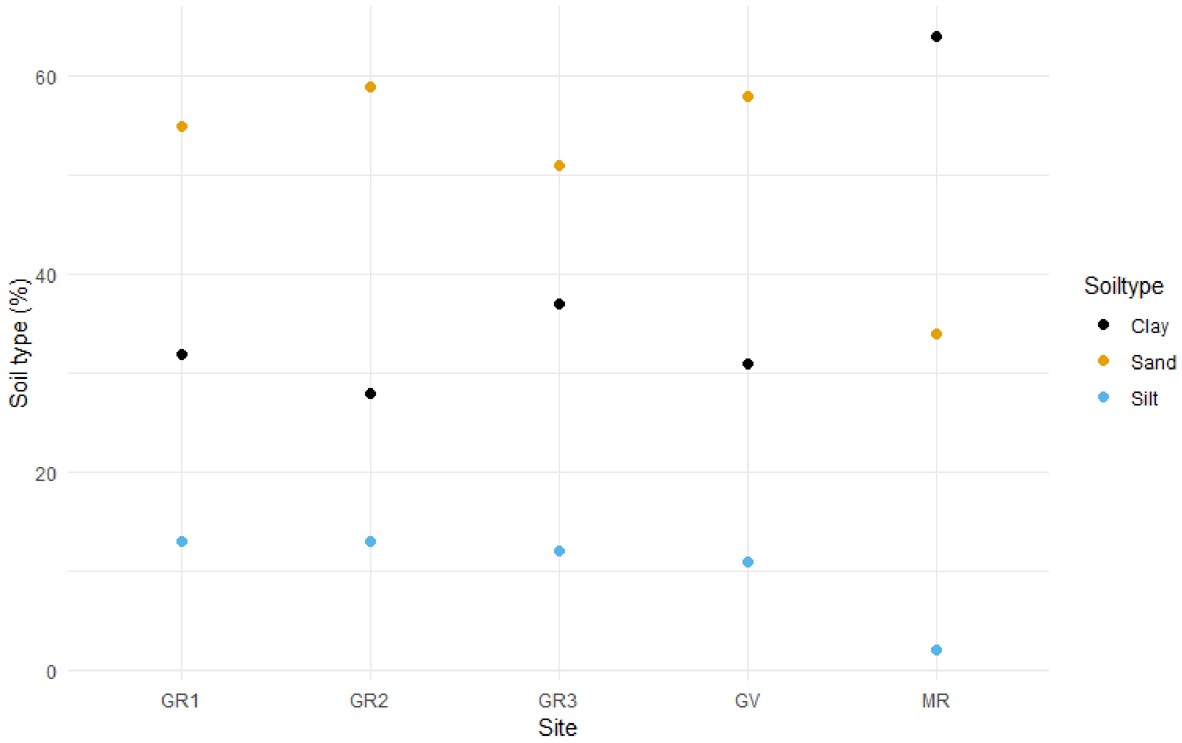

Figure 2: The distribution of particle sizes clay (< 2 µm), silt (2 - 63 µm), and sand (0.063 - 2 mm) for the five study sites (n=1).

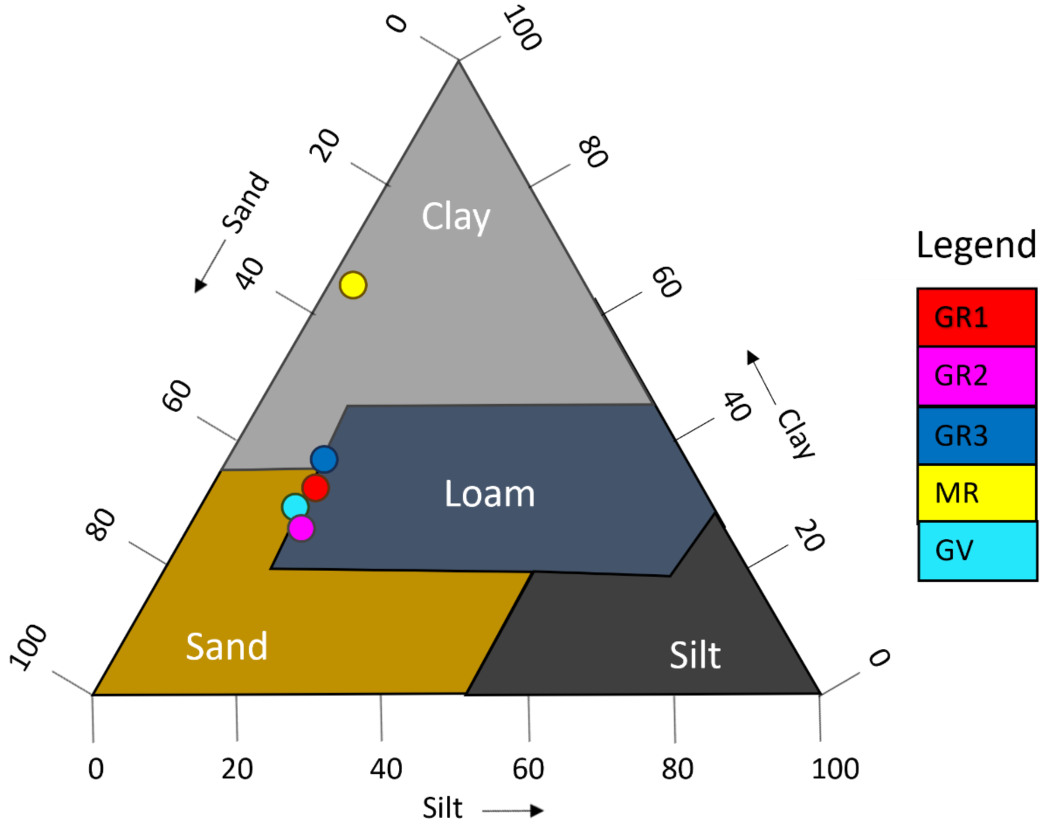

Figure 3: The classification of the soil types of the study sites within the pedological particle size triangle (according to [KA 5], own presentation).

3.1.1.2 Soil density

The soil density of the study sites ranges from 12.83 kg/L (MR) to 16.72 kg/L (GR1). The comparatively large differences between the different measurements for MR, as well as the high similarity between GR2 and GR3, are demonstrative for soil density (Figure 4). ANOVA revealed no significant differences between the study sites (Table 7).

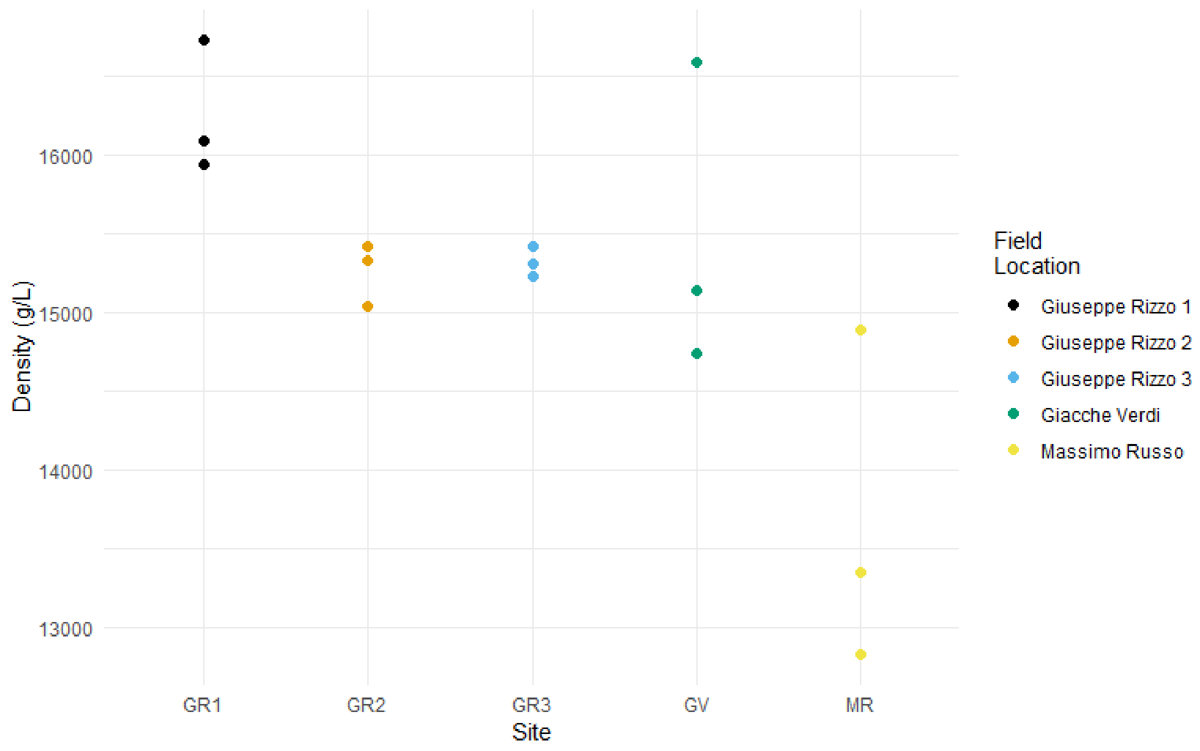

Figure 4: Soil density of the different study sites in g/L.

3.1.1.3 Water content

Regarding water content, there are only minor differences between the different study sites (Figure 5). The differences between GR1 and GR2 as well as between GR1 and GR3 are significant ($p < 0.05$, Table 7). The water content of GR1 is higher than the water content of the other study sites in every measurement except GV.

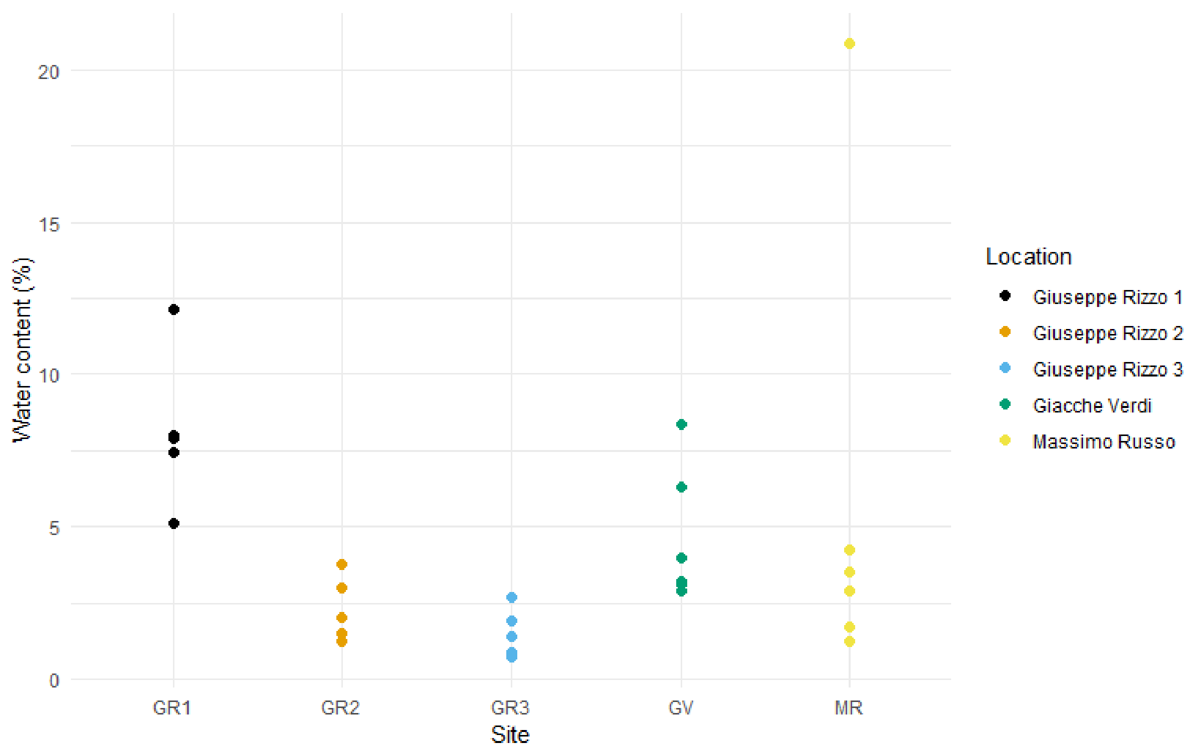

Figure 5: Water content of the different study sites recorded on 06/10/2022 (GR1), 06/11/2022 (GV, MR), and 07/29/2022 (GR2, GR3). Shown are the values of gravimetric water content for each site (n=6).

3.1.1.4 pH-values

The pH values vary between 7.14 (GR2) and 8.33 (MR, Figure 6). The study sites can thus be described as neutral to weakly alkaline. The differences between the study sites MR and GR1 as well as GR2 are highly significant ($p < 0.001$), between the study sites MR and GR3 very significant ($p < 0.01$). The differences between the study sites GV and GR1 as well as GR2 are very significant ($p<0.01$, Table 7).

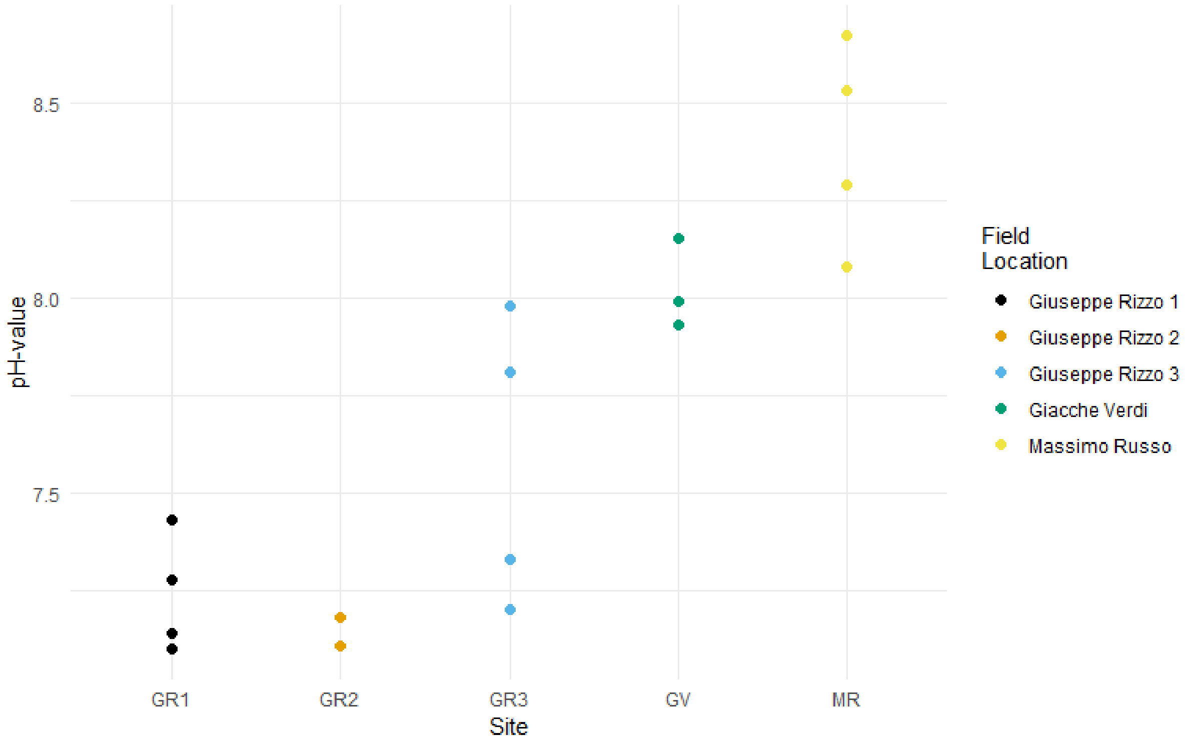

Figure 6: The pH measurements for the respective study sites (n=4, at GV there is a double measurement result at pH 7.93, in the case of GR2 n=2).

3.1.1.5 Nitrate

The nitrate values are individual measurement results without replicates, which meant that an ANOVA to analyze the differences between the study sites was not possible. While the differences between GR1, GR2, MR and GV are small to hardly present, the difference of the already mentioned study sites to GR3 is comparatively large (Figure 7).

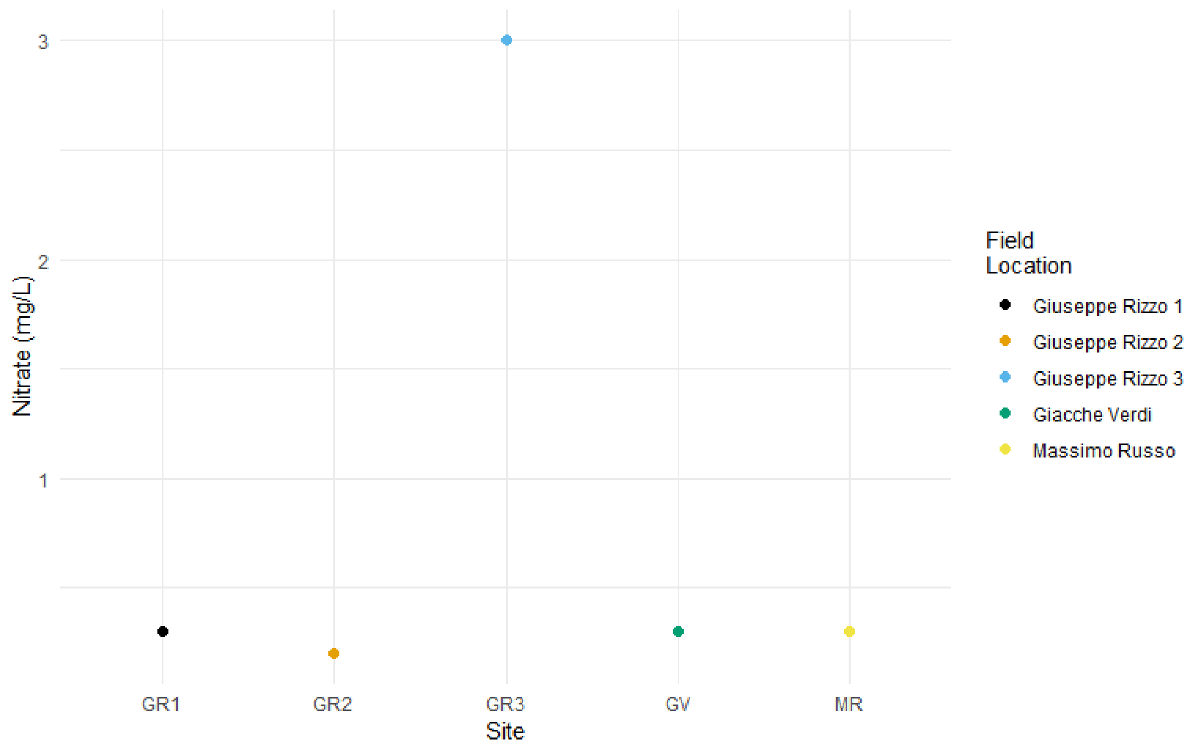

Figure 7: The nitrate concentrations (mg/L) of each study site (n=1) according to UNI EN 12457-2:2004 + APAT CNR IRSA 4020 Man 29 2003 (APAT, 2003).

3.1.2 Differences based on vegetation analysis

3.1.2.1 Coverage of the sites

Coverage of the study sites was 85-100% for GR1-3, 60-77% for GV, and 10-17% for MR (Figure 8). The differences between MR and all other sites were highly significant ($p< 0.001$). Differences between GV and GR1 as GR3 were significant ($p< 0.05$), differences between GV and GR2 were highly significant ($p< 0.01$). Indeed, the ANOVA significantly violated the assumptions of homoscedasticity and normal distribution ($p< 0.05$, Table 7).

The majority of the plots were not covered by trees (Figure 9). Only one plot has a coverage by trees, which is more than 30%.

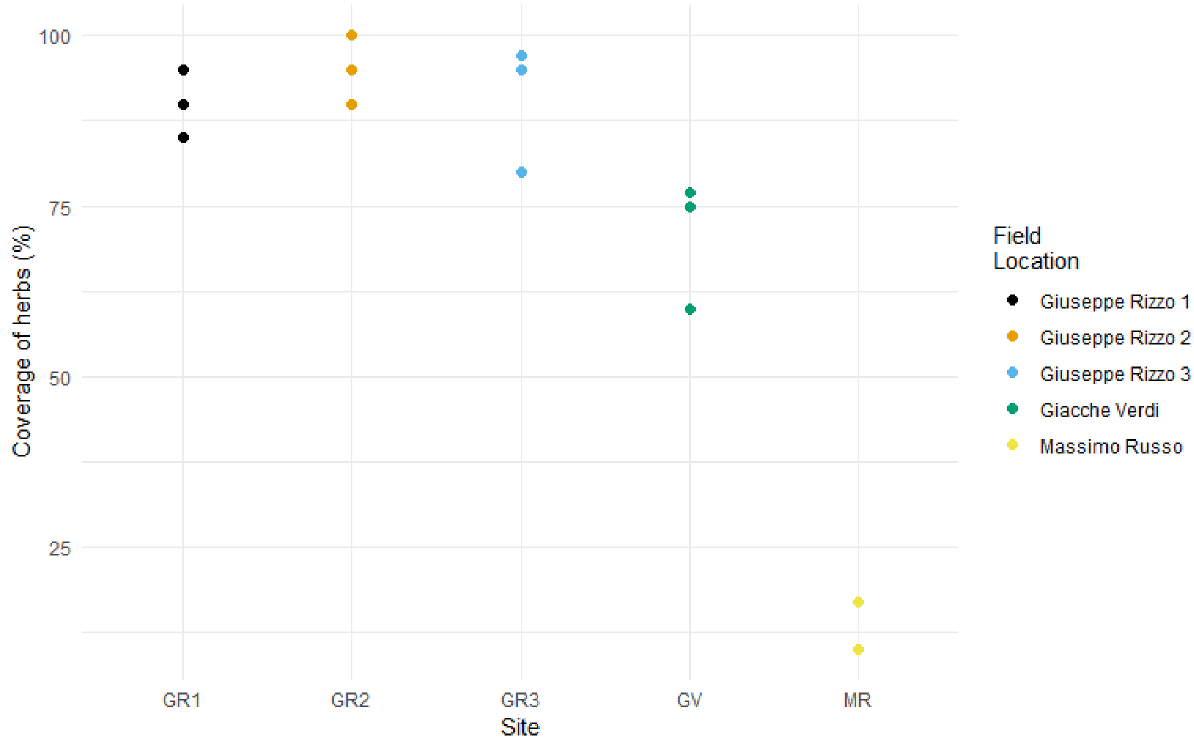

Figure 8: The coverage of herbs at the sites. For MR there are two plots with 10% coverage.

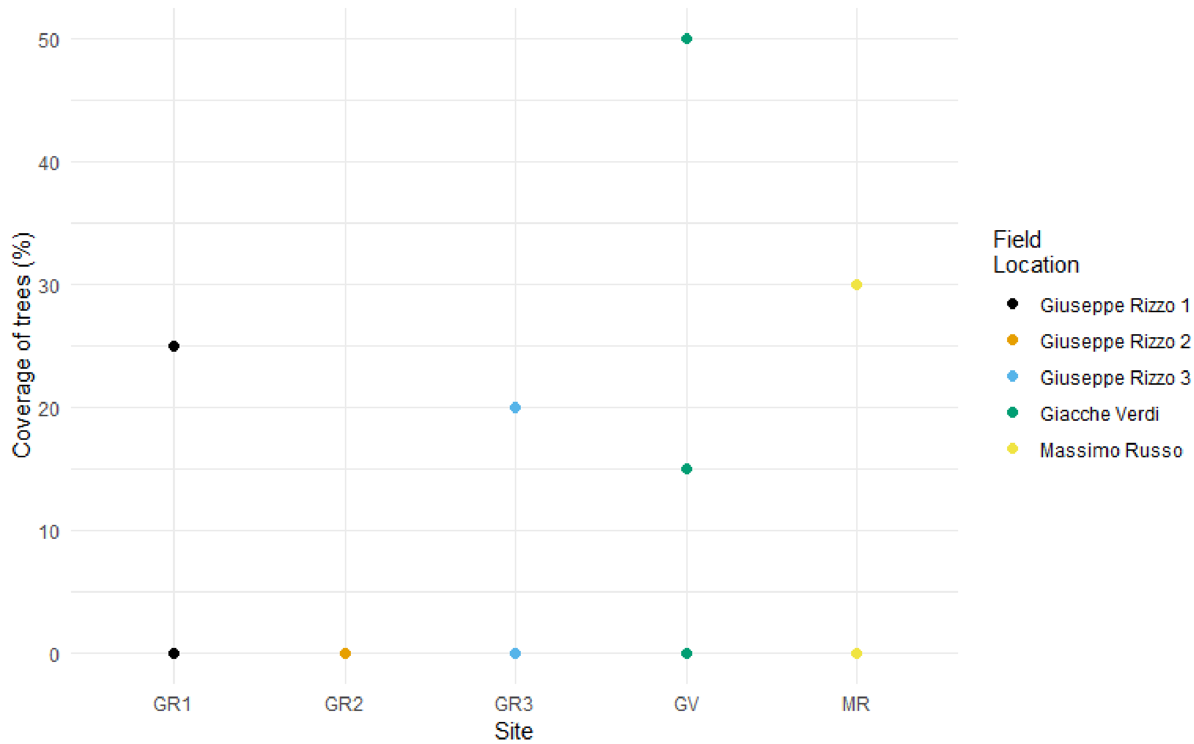

Figure 9: The coverage of trees at the sites. For GV there was one plot without coverage by trees, for GR1, GR3 and MR there were two plots without coverage by trees and for GR2 there were all plots without coverage by trees.

3.1.2.2 Weighted mean moisture EIV

With a few exceptions, the weighted mean values for moisture EIV of the individual plots are found in the range between the values three to five of the scale (Figure 10). Thus, the EIV's indicate rather dry sites, but without any particular starch-dry indicators. For the weighted moisture EIV's, no significant differences between the study sites were found using ANOVA (Table 7).

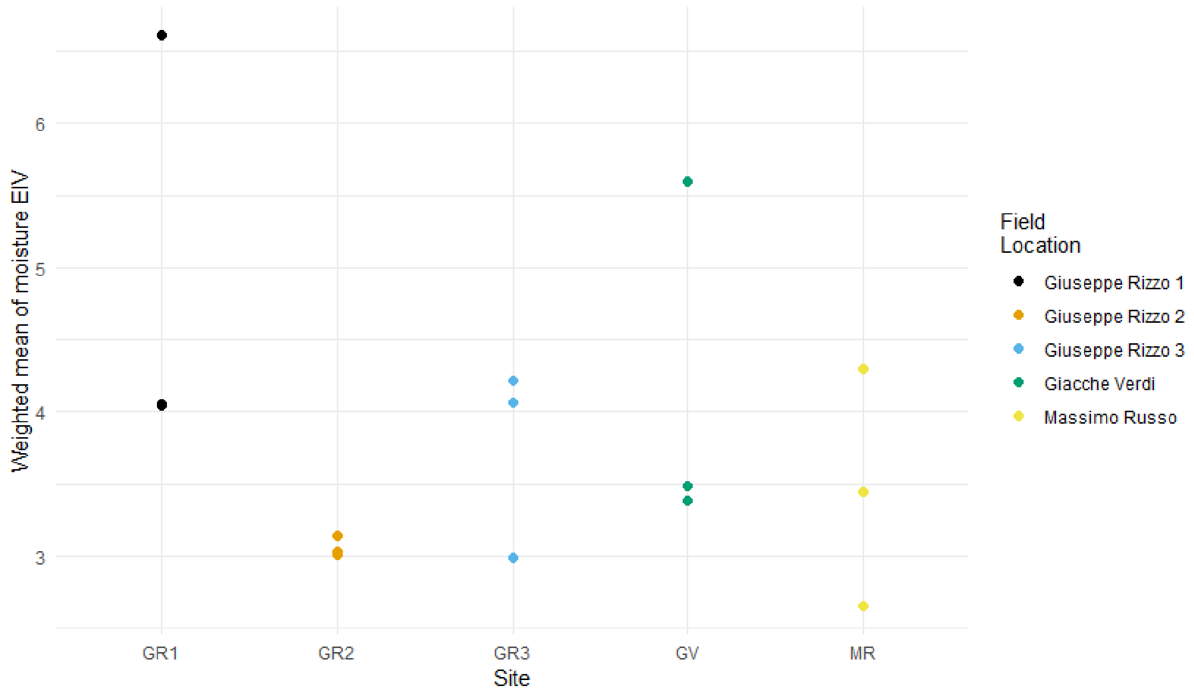

Figure 10: The weighted moisture EIV *of the study sites (n=3). For GR1, two values near pointer value 4 overlap, and for GR2, two values near pointer value 3 overlap.*

3.1.2.3 Weighted mean reaction EIV

With few exceptions, the weighted mean values for the reaction EIV of the individual plots are found in the range between the values five to seven of the scale (Figure 11). Thus, the indicator values indicate moderately to weakly acidic sites. No significant differences between the study sites were found for the weighted reaction EIV's using ANOVA (Table 7).

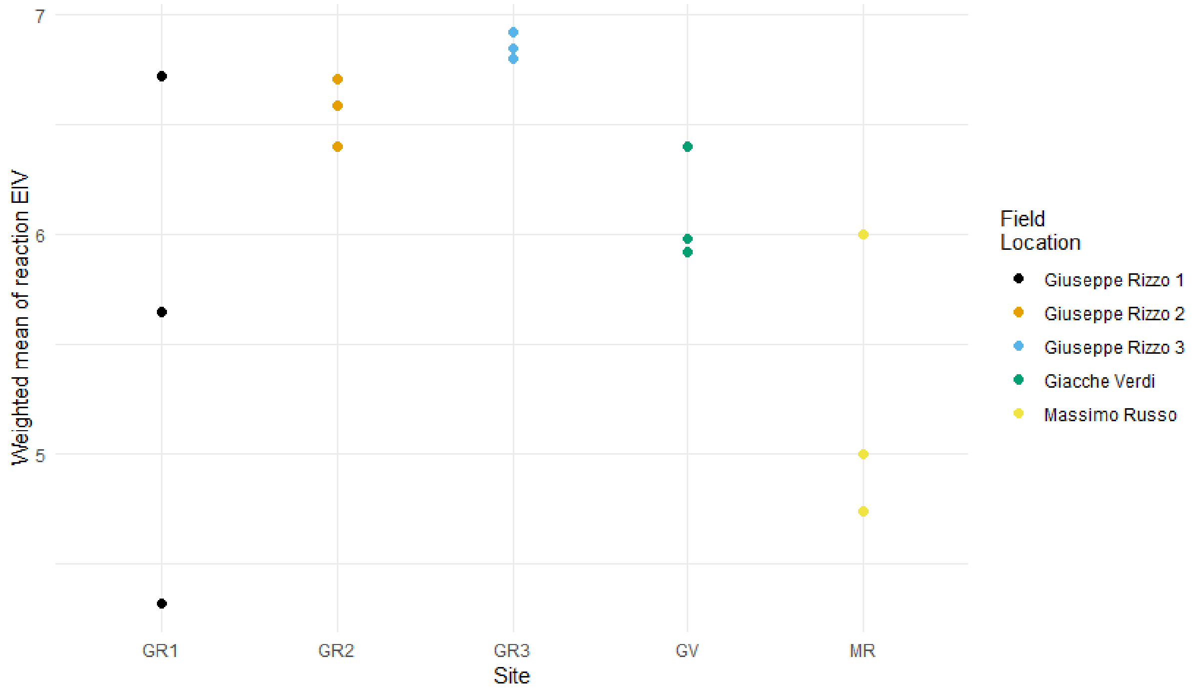

Figure 11: The weighted reaction EIV *of the study sites (n=3).*

3.1.2.4 Weighted mean nitrogen EIV

With a few exceptions, the weighted mean values for nitrogen of the individual plots are found in the range between values three to five of the scale (Figure 12). Thus, the indicator values indicate sites moderately to weakly supplied with nitrogen. For the weighted nitrogen EIV's, no significant differences between the study sites were found using ANOVA (Table 7).

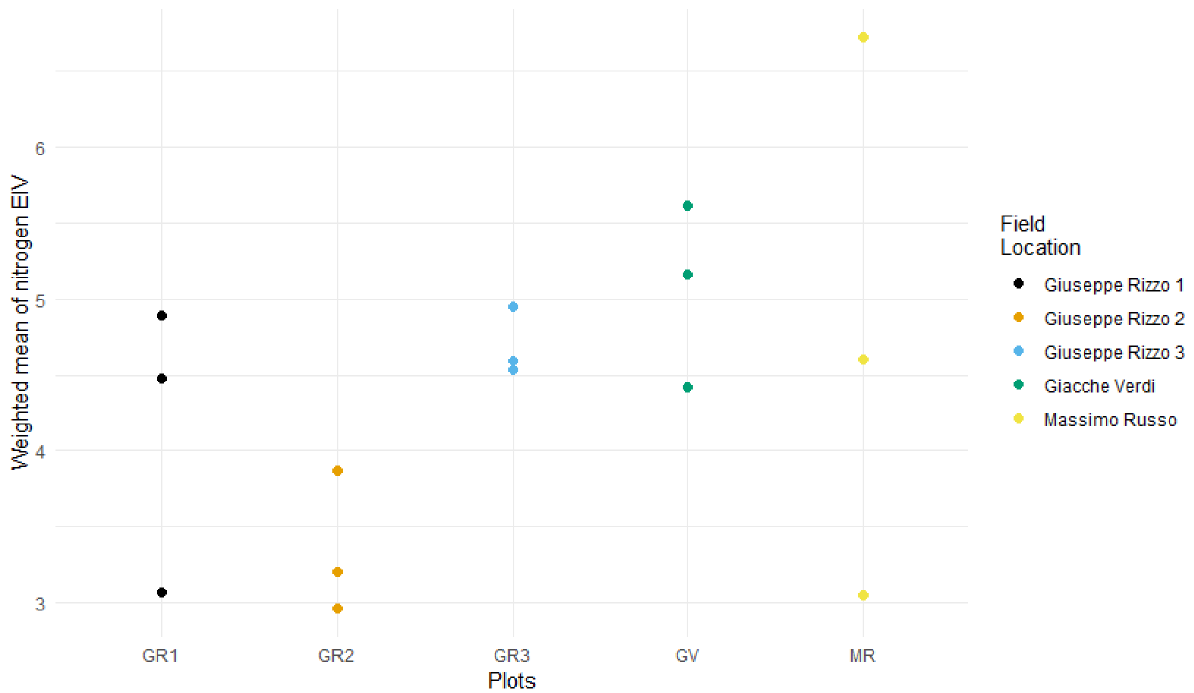

Figure 12: The weighted nitrogen EIV of the study sites (n=3).

3.2 COMPARISON OF SOIL AND VEGETATION ANALYSIS

3.2.1 Weighted mean moisture EIV – Water content

The linear model of the moisture EIV with the water content of the soil shows a significant (*p**=0.04) correlation between the two data sets studied (Figure 13, Table 3). The gradient is 0.212, the model has a coefficient of determination of R^2= 0.790 and an adjusted R^2 = 0.720.

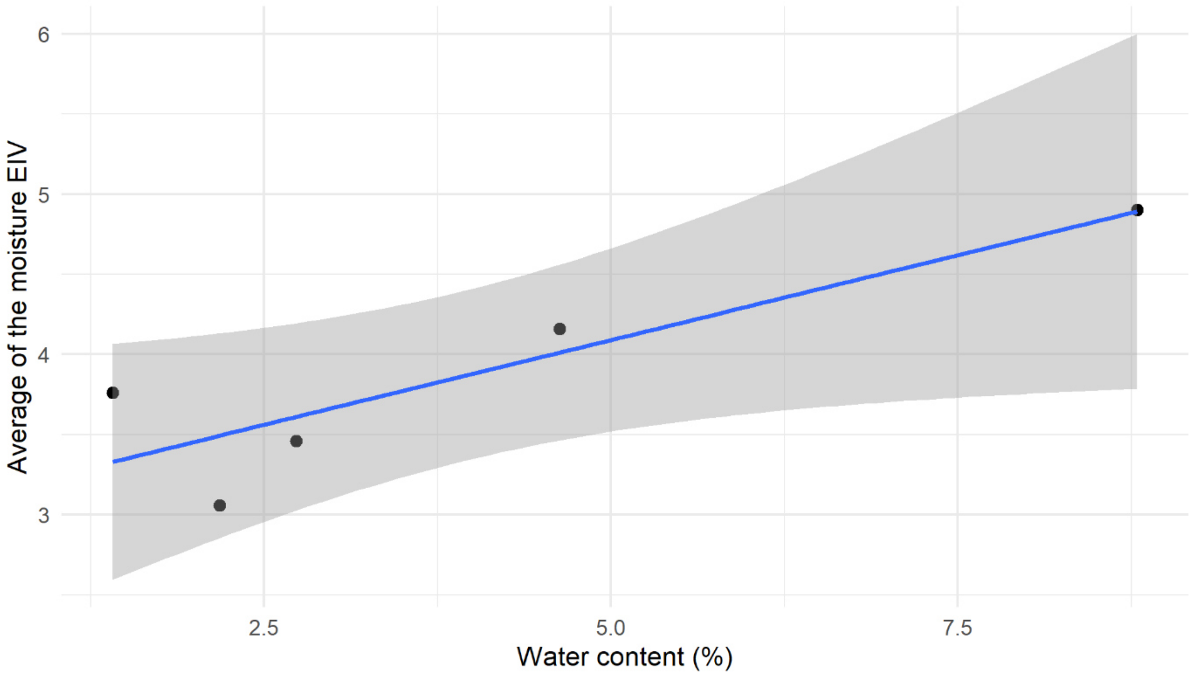

Figure 13: Correlation of the moisture EIV with the water content (%) of the soil with a confidence interval of 0.95 (n=5).

3.2.2 Weighted mean reaction EIV – pH

The linear model of reaction EIV with pH-value shows no significant (*p*>0.05) relationship between the two sets of data studied (Figure 14,Table 4).

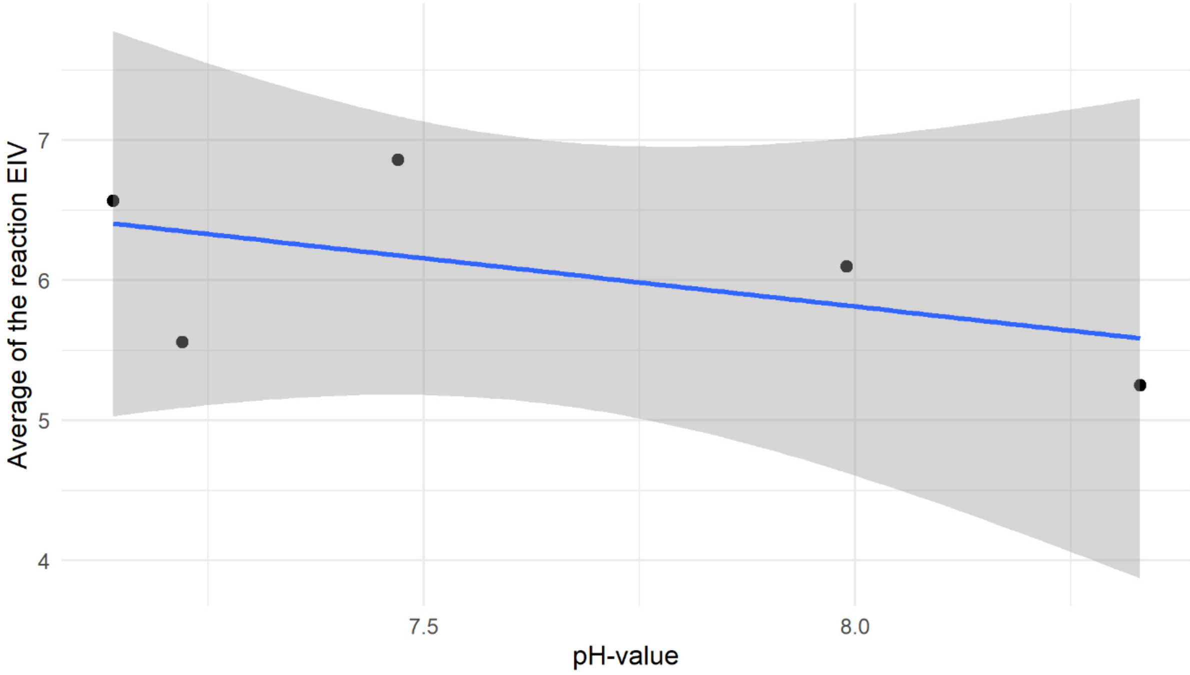

Figure 14: The linear relationship between reaction EIV and soil pH with a confidence interval of 0.95 (n=5).

3.2.3 Weighted mean nitrogen EIV – nitrate concentration

The linear model of nitrogen EIV with nitrate concentration shows no significant (p>0.05) relationship between the two sets of data studied (Figure 15, Table 5).

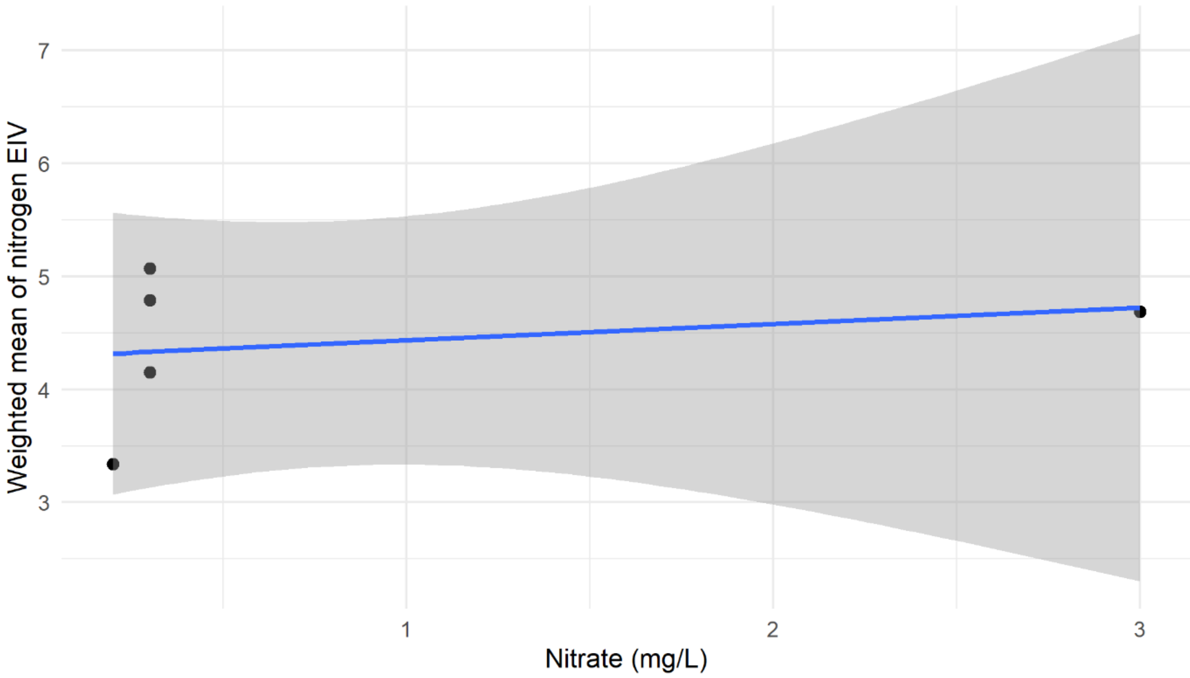

*Figure 15: The linear relationship between nitrate (mg/L) and n*itrogen EIV *with a confidence interval of 0.95 (n=5)*

3.3 CORRELATION OF THE EXISTING PARAMETERS

The corrplot shows the numerous correlations between the EIV's and the chemical and physical soil values (Figure 16). Other stronger correlations stand out that have not been investigated further.

These include the correlations between the reaction EIV and nitrate or between the nitrogen EIV and the pH value, both of which are also evaluated as significant ($p<0.05$, Figure 17,Table 6).

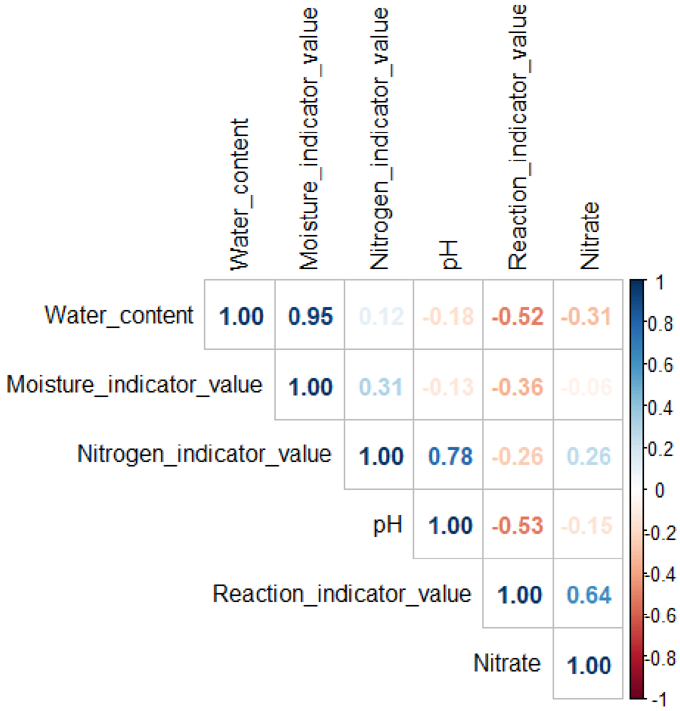

Figure 16: Corrplot to the examined data sets. The color indicates whether the correlation is positive or negative. The more clearly the numbers can be seen, the stronger the correlation is.

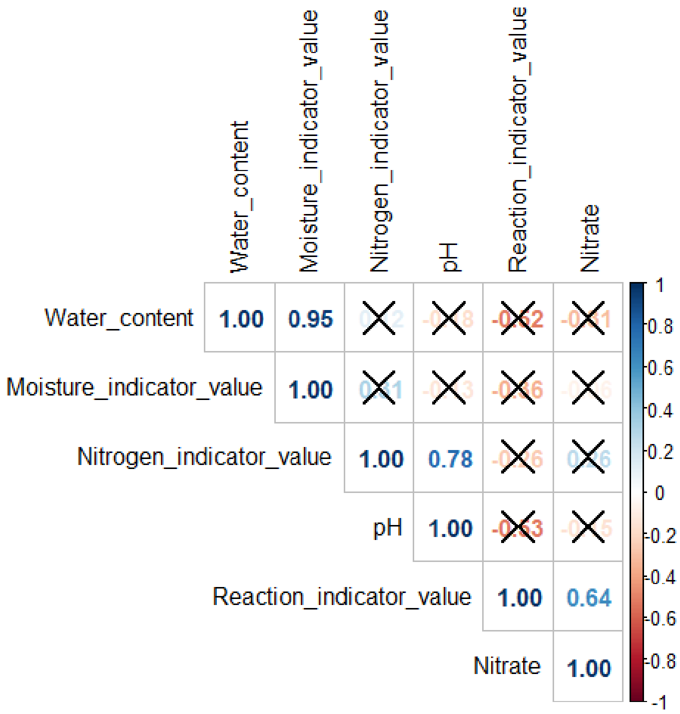

Figure 17: Corrplot to the examined data sets. The color indicates whether the correlation is positive or negative. The more clearly the numbers can be seen, the stronger the correlation is. The non-significant (p>0.05) correlations are marked with a cross.

4 DISCUSSION

4.1 DIFFERENCES BETWEEN THE STUDY SITES

The sandy clay loam is typical of the Simeto River influence area there (Albano et al., 2010). The reasons for the only minor differences between the five sites in terms of soil types, except for MR, could be associated to the parent material of the sites and the proximity to each other as well as to the Simeto River, which connects the study sites. The local differences between the GV and MR sites, which are directly adjacent to each other, are possibly because of the parent material consisting of heterogeneous landslide deposits.

The small differences regarding soil type may also result in the small differences regarding water content (Figure 5, Table 7), since this depends, among other things, on soil type. This is because, according to the equation of Hagen-Poiseuille, the water conductivity and hence the drainage of the soil is mainly related to the pore size. The pore formation in turn depends on the grain size of the soil (Amelung et al., 2018). Furthermore, the organic matter content of the soil is also relevant for the water content (Lal, 2020), but these data were not available.

Significant differences are present for the pH values of the five sites, but they are not large. All pH values are in the neutral to slightly basic range (Figure 6,Table 7). The reason for this could again be derived from the geology of the Simeto, in whose catchment area calcium-rich rocks lie and are washed out by it (Albano et al., 2010).

Nitrate levels are considered low, especially those of GR1-3 and GV (Figure 7). Unfortunately, the samples were taken after a long period of rain because there was no other chance to stay in time. This introduces the possibility of nitrate leaching, further biasing the sample (Bronson, 2008). Since the data situation for nitrate is very thin, it is difficult to interpret and justify. Caused by a high dynamic in the concentration of nitrate in the soil, a single measurement is not very meaningful (Norton, 2008).

For the EIV's, there are no significant differences between the different study sites (Table 7). One possible reason is that the study sites are quite similar in terms of geological parent material, climatic conditions, and type of cultivation. Another possible reason is that regarding the EIV's, the variances within the study sites are comparatively large, which makes significant results difficult.

The frequent differences between MR and the rest of the sites could also be because of differences in cultivation. The coverage of herbs is significantly lower compared to the other sites (Figure 8, Table 7) and in contrast to them, there is no grazing on MR. Grazing has an impact on the composition of plant species (Milchunas et al., 1988). The absent grazing could also explain why the soil density at MR is lower by trend (Figure 4). Unlike the differences between the sites regarding coverage of herbs (Figure 8), there are no significant differences between the sites regarding coverage of trees (Figure 9).

4.2 CORRELATIONS BETWEEN VEGETATION AND SOIL VALUES

The research question of whether the EIV's are suitable for drawing conclusions about soil parameters on Sicilian plantations cannot be confirmed based on the data evaluated here. While there is a significance for the correlation of moisture EIV - water content (Figure 13), this is not the case for the correlations of nitrogen EIV - nitrate concentration (Figure 15) as well as reaction EIV – pH (Figure 14). There are several possible reasons why the correlations between pH - reaction EIV and between nitrate value - nitrogen EIV are neither significant nor can explain possible correlations.

The already mentioned, comparatively high variability within the sites can also be due to inadequate selection of the investigation plots. On the vegetation side, it should also be noted that the size of the vegetation surveys is very small at 1 m². This allows for statistically larger swings. However, since EIV's are being studied and not, for example, species diversity, the number of species is of secondary importance if the species composition is representative of the site.

Another problem for the comparability of the different linear models is the heterogenous data availability of the soil values. While there were six data per study site for water content, there were only four for pH and even only one for nitrate. The sample size is thus subject to large differences. In addition to this, the sampling date for nitrate measurement is up to six months after the date of the vegetation relevé. This is problematic due to the already mentioned high dynamic of the nitrate concentration (Norton, 2008) and the danger of leaching (Bronson, 2008). The editing of the vegetation may also have caused errors, especially since the author of this bachelor thesis has so far dealt mainly with Central European flora and not with Mediterranean flora.

One possible explanation in terms of analysis is that the linear models are ultimately too monocausal. For example, the corrplot shows numerous other correlations that illustrate the complexity of the relationships between soil and vegetation (Figure 16). The numerous correlations between parameters must be considered because interactions can exist between site factors as well as between EIV's (Kunzmann, 1989). Therefore, two examples of the corrplot can be mentioned: The significant correlations of nitrogen EIV – pH and reaction EIV – nitrate concentration (Figure 17). These correlations can be explained by the process of nitrification. In this process, NH_4^+ is oxidized to NO_3^- in two partial steps, releasing two H^+ per NH_4^+ (Amelung et al., 2018). The interactions between the parameters put the importance of a single parameter for another into perspective, weakening the correlation of two parameters, such as pH with the reaction EIV.

Differentiated from errors in experimental design or during recording, an explanation to the difficulties with correlations could lie with the EIVs themselves. First, the respective EIV's do not represent individual soil parameters, but rather a group of parameters instead. For example, the moisture EIV may be influenced by groundwater or soil water content, and the nitrogen EIV may correlate with biomass rather than nitrate concentration (Schaffers & Sýkora, 2000). In part, therefore, there are recommendations to reclassify the EIV's because they correlate with certain parameters better than the name suggests. For example, there are efforts to rename the reaction EIV to calcium EIV or the nitrogen EIV to a production EIV (Franzaring et al., 2012; Schaffers & Sýkora, 2000). This makes direct comparison of EIV's to specific soil values more difficult (Schaffers & Sýkora, 2000). In addition, the EIV's represent only relative increments, which also results in the ordinal data structure, and are also not intended to replace individual measurements (Ellenberg et al., 2001). While this does not argue against the use of EIV's to characterize, for example, an olive grove, it is problematic for the approach taken in this work due to small data sets and makes it difficult to compare EIV's with chemical and physical data. In perspective, it is likely that the trends of EIV's will become clearer with larger data sets.

Another reason for missing two correlations could be the strategic orientation of the vegetation. Since agriculturally managed areas are frequently disturbed, these areas are typical sites for ruderal species (Grime, 2006). The study sites are all grazed except for MR, which favors ruderal species as a form of disturbance. Site MR is a site for ruderal species anyway due to low vegetation cover (Grime, 2006). Vegetation in a regeneration stage can deviate significantly from the EIV's (Ellenberg et al., 2001). Separate EIV's for disturbance have since been developed to address this problem (Midolo et al., 2023), and should be considered for research of this kind in the future. In this work, it was unfortunately not possible to include them due to the short-term nature. Thus, if soil disturbance is the most important parameter for the plants present, this could in turn weaken the importance of the reaction and nitrogen supply parameters studied and thus the respective correlations.

Furthermore, one more reason could be that the study sites are too similar, as already mentioned. The climatic and geological conditions of the study sites are almost the same, as well as the management. The similarity of the study sites is also indicated by the analyses for difference (ANOVA) of the study sites with respect to soil and vegetation data, which found significant differences between the study sites only in exceptional cases. Furthermore, it is important to note in this context that significant differences are not necessarily meaningful. The frequent lack of significance in the differences between the study sites was also partly due to variances within the study sites (especially MR), but these were also often similar. This has a negative effect on the correlation analyses, in addition the EIV's are not completely reliable when having only little differences between the sites (Ellenberg et al., 2001). What supports the method against this background is that both the respective soil values and the vegetation values were similar to each other. This can be seen particularly well in Figure 5Figure 6 Figure 10. It follows from the common minor differences in the respective data sets that the effectiveness of the method cannot be refuted with the available data sets. Consequently, we can expect that with larger and more diverse data sets, meaningful correlations may well emerge.

Thus, there are several reasons why correlations for the nitrogen EIV as well as the reaction EIV could not be confirmed in this experimental design. That the correlation with the Moisture-EIV yielded a significant result including a high coefficient of determination was possibly due to the much broader data base and the stronger differences between the study sites. Going further, it can also be argued that drought stress is the limiting factor in Mediterranean ecosystems (Pfadenhauer & Klötzli, 2014), which is why there is a significant correlation here. The other parameters would thus fade into the background. In general, however, the Moisture EIV is also considered the core of the EIV's (Böcker et al., 1983) as well as the EIV considered best secured by Ellenberg himself (Ellenberg et al., 2001).

4.3 CONCLUSION

From the data, the EIV's regarding the application on Sicilian plantations cannot be confirmed. However, since problems of research design and execution can be cited as the main reasons for this, the data also do not indicate a rejection of the application of EIV's on Sicilian plantations yet. A larger study setup and an extended statistical evaluation are needed to answer whether the EIV's are suitable to characterize the soil of Sicilian plantations. This should include more data and, for meaningful correlations, particular attention to differences between the study sites should be paid. These should include parent rock, exposure, inclination and, if possible, mean annual precipitation.

Appendix

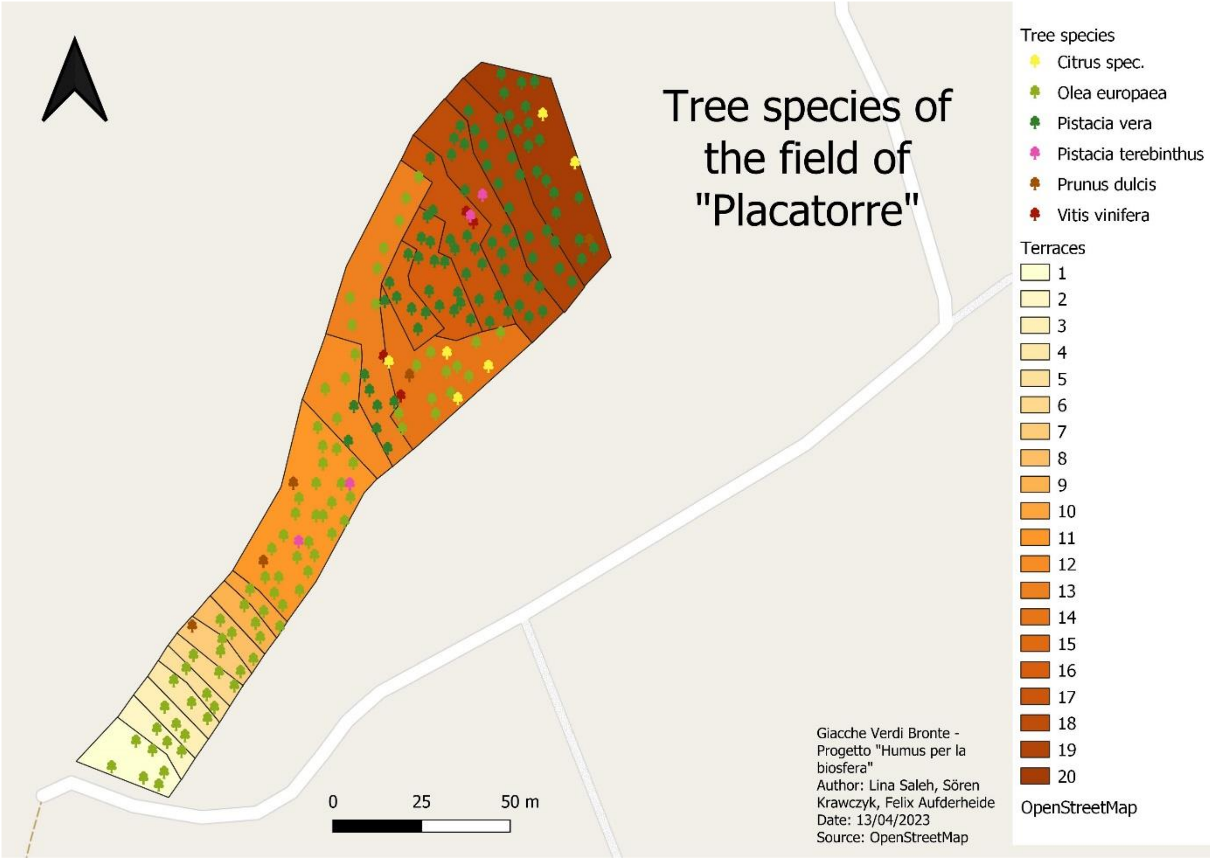

Figure 18: Tree species and structure of the field Placatorre (GV)

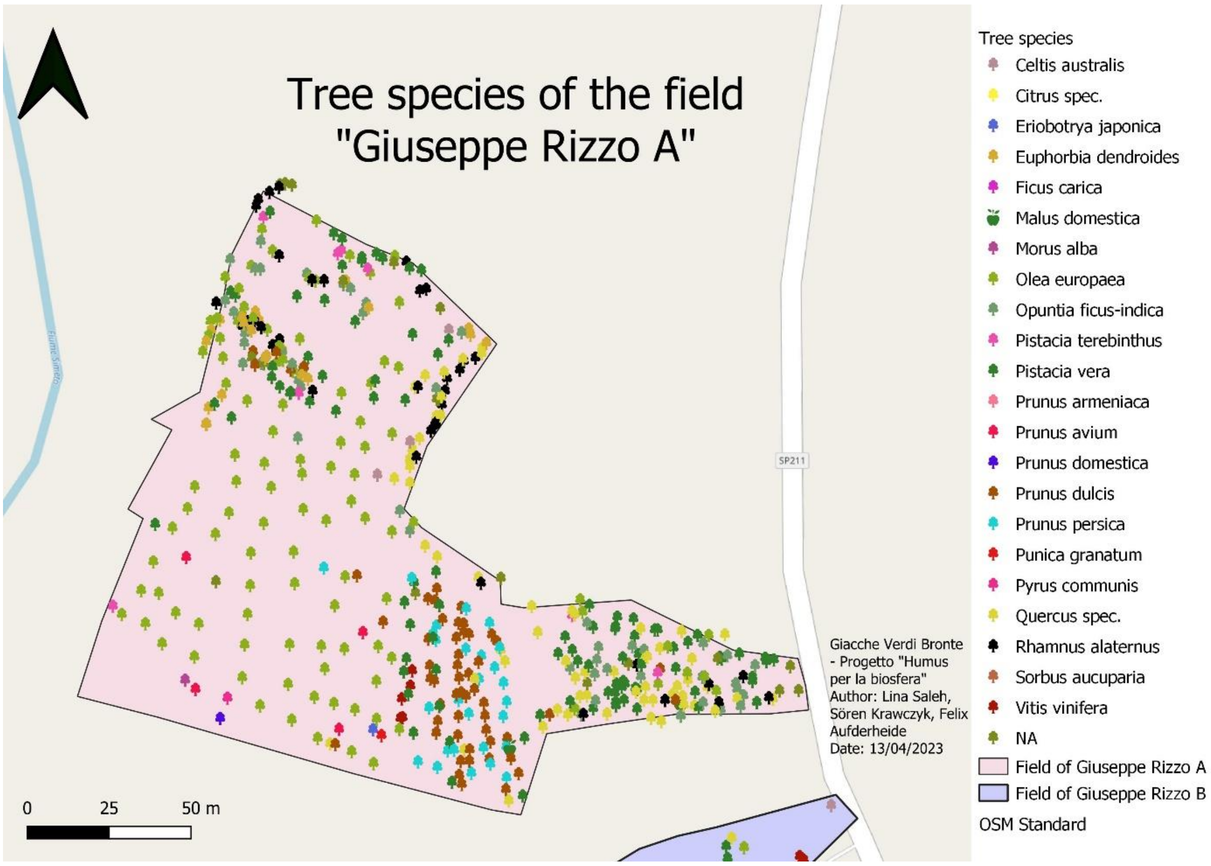

Figure 19: Tree species of the field "Giuseppe Rizzo A"

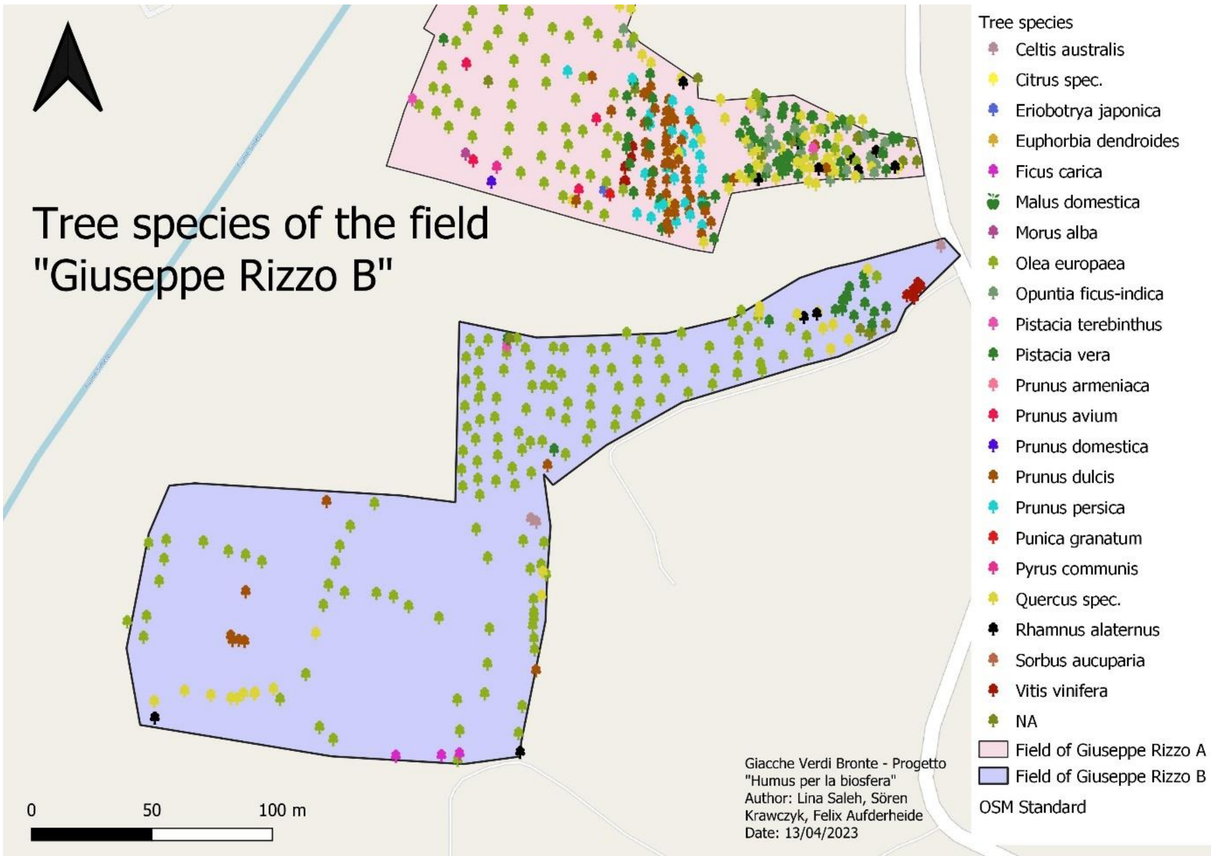

Figure 20: Tree species of the field "Giuseppe Rizzo B"

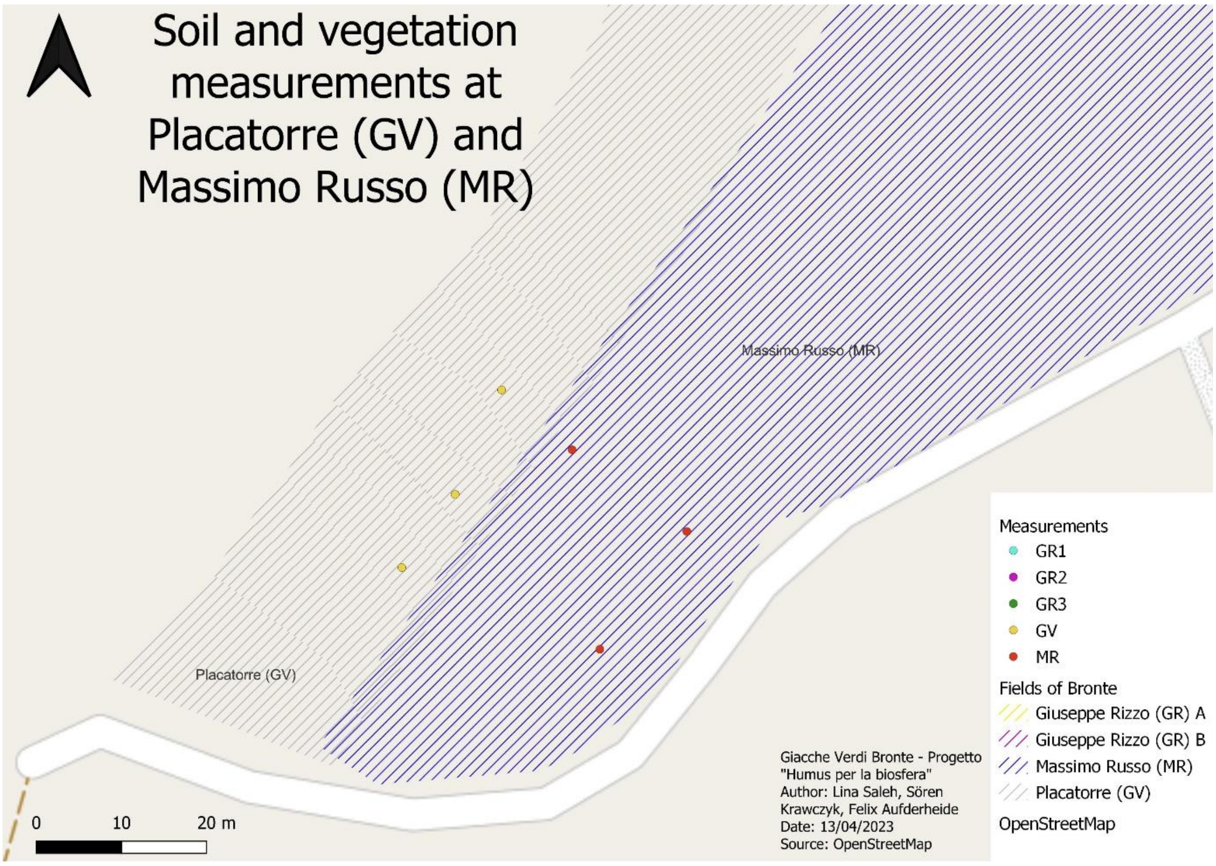

Figure 21: Soil and vegetation measurements at the fields Placatorre (GV) and Massimo Russo (MR)

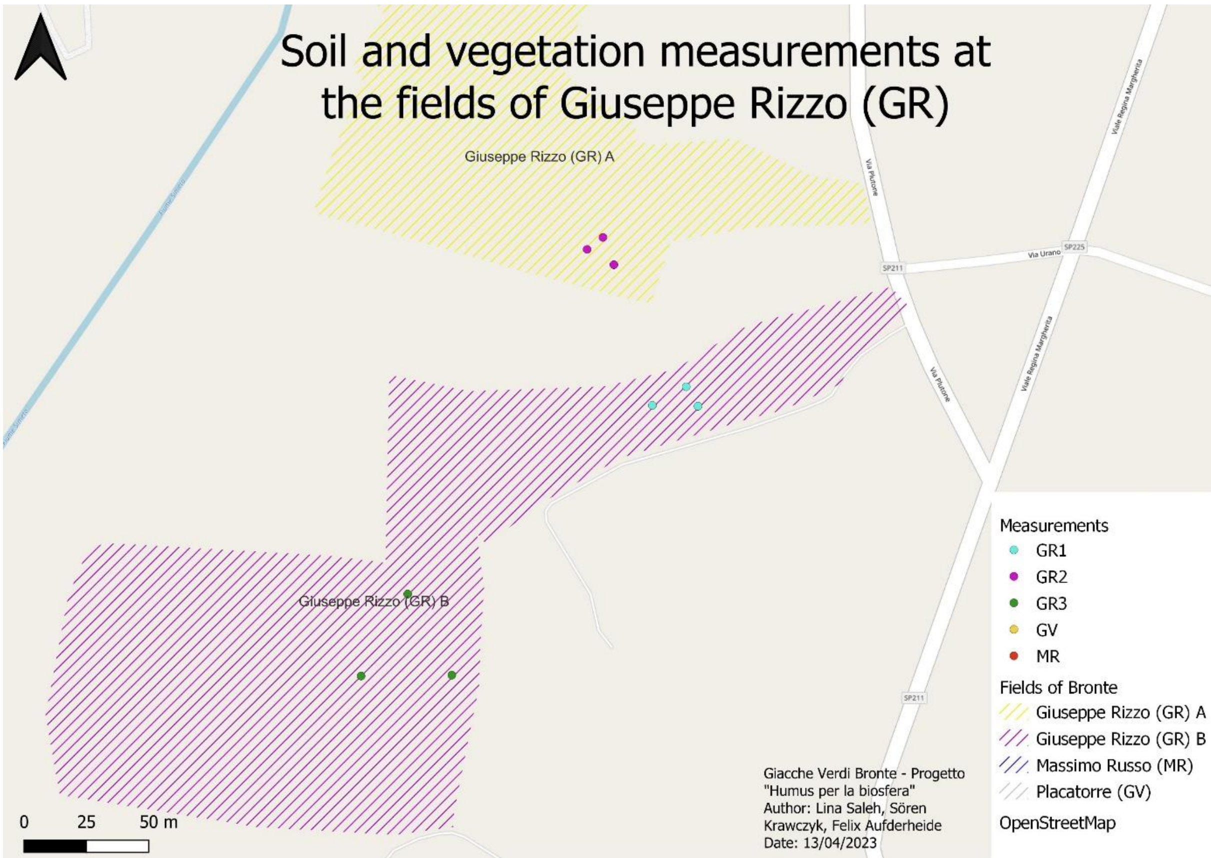

Figure 22: Soil and vegetation measurements of the fields of Giuseppe Rizzo (GR)

Table 1: Indicator value calculation, field and ground data (Water content 1= Water content of water content measurement and density measurements (%, 6 values), Water content 2= Water content of water content measurement, water content 3= Water content of density measurement (%))

Plot	GR1.1	GR1.2	GR1.3	GR2.1	GR2.2	GR2.3	GR3.1	GR3.2	GR3.3	MR1.1	MR1.2	MR1.3	GV1.1	GV1.2	GV1.3
Number of species	11	10	10	8	11	9	7	14	5	10	10	8	15	13	13
Total coverage (%)	53.6	61.6	91.7	61.6	53.6	98.7	94.7	53.9	111.1	3.6	3.2	3.6	27.5	53.4	28.8
Coverage of trees (%)	25	0	0	0	0	0	20	0	0	30	0	0	50	15	0
Coverage of herbs (%)	85	95	90	100	90	95	80	95	97	10	17	10	77	75	60
Altitude (cm)	20	25	35	70	70	55	20	25	15	12	33	15	8	6	7
Exposition	/	/	/	/	/	/	/	/	/	S	SO	SO	NW	W	SW
Inklination	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.08	0.10	0.02	0.02	0.01
Unweighted mean EIV moisture	4.55	4.70	3.95	3.50	4.00	3.57	4.57	4.54	3.20	3.38	3.22	4.30	3.60	3.75	3.45
Weighted mean EIV moisture	6.61	4.05	4.04	3.03	3.14	3.01	4.22	4.06	2.99	3.44	2.65	4.30	3.49	5.60	3.38
Unweighted mean EIV reaction	6.10	5.89	5.67	6.00	6.30	6.71	6.29	6.25	6.60	5.50	5.11	5.00	6.44	5.70	6.10
Weighted mean EIV reaction	4.32	6.72	5.65	6.59	6.71	6.40	6.80	6.92	6.85	6.00	4.74	5.00	5.98	5.92	6.40
Unweighted mean EIV nitrogen	5.91	5.50	5.55	5.25	5.27	5.29	5.86	5.62	5.60	5.44	4.61	4.60	4.35	4.96	5.14
Weighted mean EIV nitrogen	3.07	4.89	4.48	3.20	2.96	3.87	4.59	4.53	4.95	6.72	3.05	4.60	4.42	5.61	5.16
Shannon-Wiener index	1.05	1.19	1.45	0.93	1.05	1.22	0.93	1.08	0.96	1.86	1.78	2.02	1.17	1.04	1.26
Evenness	0.44	0.52	0.63	0.45	0.44	0.56	0.48	0.41	0.59	0.81	0.77	0.97	0.43	0.40	0.49
pH	7.22	7.22	7.22	7.14	7.14	7.14	7.47	7.47	7.47	8.33	8.33	8.33	7.99	7.99	7.99
Water content 1 (%)	8.79	8.79	8.79	2.18	2.18	2.18	1.41	1.41	1.41	2.73	2.73	2.73	4.63	4.63	4.63
Water content 2 (%)	8.02	5.13	7.88	1.51	3.76	3.02	0.85	0.71	0.88	1.72	4.23	20.85	8.35	3.18	4.00
Water content 3 (%)	7.43	12.14	12.12	1.25	1.52	2.02	1.41	1.90	2.71	3.53	2.91	1.24	6.29	2.91	3.08
Clay (%)	32	32	32	28	28	28	37	37	37	64	64	64	31	31	31
Silt (%)	13	13	13	13	13	13	12	12	12	2	2	2	11	11	11
Sand (%)	55	55	55	59	59	59	51	51	51	34	34	34	58	58	58
Nitrate (mg/L)	0.3	0.3	0.3	0.2	0.2	0.2	3.0	3.0	3.0	0.3	0.3	0.3	0.3	0.3	0.3
Density (g/L)	16723.2	15942.4	16091.2	15043.2	15417.6	15324.8	15232.0	15420.8	15307.2	14892.8	13355.2	12832.0	14740.8	16585.6	15136.0

Table 2: Data of the vegetation found at the sites. For the Ellenberg indicator values the average ones for Italy were chosen (Tichý et al., 2023)

Location	Moisture	Reaction	Nitrogen	GR1.1	GR1.2	GR1.3	GR2.1	GR2.2	GR2.3	GR3.1	GR3.2	GR3.3	MR1.1	MR1.2	MR1.3	GV1.1	GV1.2	GV1.3
Agrostis stolonifera	7	NA	6	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0
Allium spec.	NA	NA	NA	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
Anagallis arvensis	5	2	3.5	0	0	0	0	0	0	0	0	0	0.1	0.1	0.5	0.5	0.1	0.5
Armeria spec.	NA	NA	NA	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
Asparagus aphyllus	2	5	2	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0
Avena barbata	3	7	2	0	0	0	37.5	37.5	37.5	0	0	0	0	0	0	0	0	0
Beta vulgaris	6	6	5	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0
Borago officinalis	3	5	5	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0
Brassica rapa	4	7	7	0	0	0	0.1	0.1	0	10	0.1	0	0	0	0	0	0	0
Bromus hordeaceus	NA	NA	NA	0	0	0	0	0	0.1	0	0	0	0	0	0	20.5	37.5	20.5
Bromus sterilis	NA	NA	NA	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Calendula arvensis	3	8	5	10	37.5	20.5	0	0	1	62.5	37.5	37.5	0	0	0	0	0	0.5
Cardamine hirsuta	3	5	4	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
Chamaemelum fuscatum	8	3	2	37.5	10	20.5	0	0	0	20.5	10	0	0	0	0	0	0	0
Digitaria spec.	NA	NA	NA	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0	0
Ecballium elaterium	3	5	8	0	0	0	0	0	0	0	0	0	0.5	0.1	0	0	0	0
Echium plantagineum	3	5	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Erigeron bonariensis	3	NA	7	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
Erodium ciconium	2	5	5	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0
Erodium malacoides	2	5	6	0.5	0	10	0	0	0	0	0	0	0	0	0	0	0	0.1
Euphorbia exigua	2	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0
Euphorbia helioscopa	3	5	6	0.5	0.5	0.5	0	0	0	0	0.1	0	0	0	0	0	0.1	0
Ficaria verna	6	7	7	0	0	0	0	1	0.1	0	0	0	0	0	0	0	0	0
Filago pygmaea	2	3	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Galactites tomentosus	4	6	7	0	10	0	0	0	0	0.5	0	0	0	0	0	0	0.5	1
Geranium dissectum	5	5	5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Glebionis segetum	5	5	5	1	0.5	0.5	0	0	0	0	0.5	0.1	0	0	0	0	0	0
Hedysarum coronarium	5	7	4	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0
Hypericum perforatum	NA	NA	NA	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0
Hypochaeris achyrophorus	3	NA	3	0	0	0	0	0.5	0	0	0	0	0	0	0	1	1	1
Hypochaeris spec.	NA	NA	NA	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0
Kickxia commutata	4	5	4	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0

Location	Moisture	Reaction	Nitrogen	GR1.1	GR1.2	GR1.3	GR2.1	GR2.2	GR2.3	GR3.1	GR3.2	GR3.3	MR1.1	MR1.2	MR1.3	GV1.1	GV1.2	GV1.3
Lactuca spec.	NA	NA	NA	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0
Lamium amplexicaule	4	5	7	0	0	0	0	0	0	0	0	0	0	0.1	0.5	0	0	0
Lotus tetragonolobus	6	9	6	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0
Malva spec	NA	NA	NA	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
Medicago littoralis	2	7	5	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0	0
Medicago orbicularis	3	6	5	0	0	0	20.5	1	20.5	0	0	0	0	0.1	0	1	1	1
Medicago x varia	3	9	5	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	1
Mercurialis annua	5.5	7	4.5	0	0	0.1	0	0	0	0	0	0	0	0	0.5	0	0	0
Mycelis muralis	5	NA	6	0.1	0	1	0	0	0	0	0.1	0	0	0	0	0	0	0
Oxalis pes caprae	3	6	5	0	1	37.5	1	10	37.5	0	1	62.5	0	0	0	0.5	1	0
Papaver rhoeas	5	7	6	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0
Phedimus spurius	NA	NA	NA	0	0	0	0	0	0	0	0	0	1	0	0.5	0	0	0
Plantago monosperma	NA	NA	NA	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0
Quercus spec.	NA	NA	NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1
Rumex acetosa	5	4	5	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0
Rumex patientia	3	6	7	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
Rumex pulcher	2	6	9	1	0	0.1	0	0	0	0.1	0.5	1	0	0	0	0	0	0
Scandix pecten-veneris	3	8	4	1	0	0	0	0	0	0	1	10	0	0	0	0.5	0	0
Scorpiurus muricatus	3	6	4	0	0	0	0	0	0	0	0	0	0.1	1	0.5	0	0.5	1
Senecio vulgaris	5	6	8	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sherardia arvensis	5	6	5	0	0	0	0	0.5	0	0	0.1	0	0	0	0	0	0	0.1
Sinapis arvensis	5	8	6	0	0.1	0	0	0	0	1	1	0	0	0	0	0	0	0
Sonchus oleraceus	4	8	8	1	0	0	0.5	0.5	0.5	0	0	0	0.5	0	0	0	0.5	1
Vicia hybrida	3	5	5	0	0	0	1	1	1	0	0	0	0	0	0	1	1	1
Veronica arvensis	5	6	6	0	0	0	0	0.5	0	0	0	0	0.1	0	0	0	0	0
Veronica beccabunga	10	7	6	0.5	0.5	0	0	0	0	0	0.5	0	0	0	0	0	0	0
Gesamtbedeckung	NA	NA	NA	53.6	61.6	91.7	61.6	53.6	98.7	94.7	53.9	111.1	3.6	3.2	3.6	27.5	53.4	28.8
Bedeckung Baum	NA	NA	NA	25	0	0	0	0	0	20	0	0	30	0	0	50	15	0
Bedeckung Kraut	NA	NA	NA	85	95	90	100	90	95	80	95	97	10	17	10	77	75	60
Hoehe	NA	NA	NA	20	25	35	70	70	55	20	25	15	12	33	15	8	6	7
Exposition	NA	NA	NA	/	/	/	/	/	/	/	/	/	S	SO	SO	NW	W	SW
Inklination	NA	NA	NA	0	0	0	0	0	0	0	0	0	0.06	0.08	0.1	0.015	0.02	0.01

Table 3: Linear model of weighted mean moisture EIV and water content (%).

Linear model of weighted mean moisture indicator values and water content (%)

	Dependent variable:
	Weighted mean moisture indicator value
Water content (%)	0.212**
	(0.063)
Constant	3.033***
	(0.300)
Observations	5
R^2	0.790
Adjusted R^2	0.720
Residual Std. Error	0.373 (df = 3)
F Statistic	11.261** (df = 1; 3)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 4: Linear model of weighted mean reaction EIV and pH.

Linear model of weighted mean reaction indicator values and pH

	Dependent variable:
	Weighted mean reaction indicator value
pH	-0.689
	(0.643)
Constant	11.323
	(4.917)
Observations	5
R^2	0.276
Adjusted R^2	0.035
Residual Std. Error	0.660 (df = 3)
F Statistic	1.146 (df = 1; 3)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 5: Linear model of weighted mean nitrogen EIV and nitrate (%).

Linear model of weighted mean nitrogen indicator values and nitrate	
	Dependent variable:
	Weighted mean nitrogen indicator value
Nitrate (%)	0.146
	(0.313)
Constant	4.288^{***}
	(0.427)
Observations	5
R^2	0.068
Adjusted R^2	-0.243
Residual Std. Error	0.762 (df = 3)
F Statistic	0.218 (df = 1; 3)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 6: Correlations of several parameters.

Variable	1	2	3	4	5
1. Water content					
2. Moisture EIV	.99**				
3. Nitrogen EIV	.04	.06			
4. pH	-.10	-.12	.94**		
5. Reaction EIV	-.71	-.66	-.62	-.61	
6. Nitrate	-.73	-.64	-.28	-.36	.89*

Note. * indicates p <0.05. ** indicates p <0.01.

Table 7: ANOVA's and pairwise comparisons using t tests of the weighted mean EIVS, water content, pH, soil density and coverage of the herbs (t tests only with significant results (p< 0.05))

```
ANOVA Weighted mean moisture EIV - Site
               Df Sum Sq Mean Sq F value Pr(>F)
data_plot$Site  4  5.932  1.4830   1.516   0.27
Residuals      10  9.783  0.9783

ANOVA Weighted mean reaction EIV - Site
               Df Sum Sq Mean Sq F value Pr(>F)
data_plot$Site  4  5.403  1.3507   3.403 0.0529 .
Residuals      10  3.969  0.3969

ANOVA Weighted mean nitrogen EIV - Site
               Df Sum Sq Mean Sq F value Pr(>F)
data_plot$Site  4  5.570  1.3925   1.409    0.3
Residuals      10  9.882  0.9882

ANOVA Water content - Site
                  Df Sum Sq Mean Sq F value Pr(>F)
data_wc2$Site_num  1   13.5   13.45   0.688  0.414
Residuals         28  547.1   19.54

Pairwise comparisons using t tests with pooled SD Water content - Site
  1     2     3     4
2 0.048 -     -     -
3 0.022 1.000 -     -
4 0.744 0.671 0.449 -
5 0.467 0.802 0.744 1.000

ANOVA pH - Site
                 Df Sum Sq Mean Sq F value   Pr(>F)
data_pH$Site_num  1  2.606  2.6055    21.8 0.000257 ***
Residuals        16  1.912  0.1195

Pairwise comparisons using t tests with pooled SD pH - Site
  1       2       3       4
2 0.65874 -       -       -
3 0.15985 0.15985 -       -
4 0.00011 0.00034 0.00248 -
5 0.00373 0.00650 0.12962 0.14120

ANOVA Density - Site
                    Df   Sum Sq Mean Sq F value Pr(>F)
data_plot_dens$Site  1  2879529 2879529   3.075  0.103
Residuals           13 12174581  936506

ANOVA Coverage of herbs - Site
                    Df Sum Sq Mean Sq F value Pr(>F)
data_plot_dens$Site  1   4417    4417   5.547 0.0349 *
Residuals           13  10350     796

Pairwise comparisons using t tests with pooled SD Coverage of herbs -
Site
  1       2       3       4
2 1.0000  -       -       -
3 1.0000  1.0000  -       -
4 6.6e-07 4.4e-07 6.6e-07 -
5 0.0267  0.0092  0.0267  8.2e-06

---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
P value adjustment method: holm
```

Statement on Plagiarism

Erklärung der / des Studierenden

Hiermit versichere ich, dass ich die vorliegende Arbeit über

Are the Ellenberg indicator values suitable for characterizing soils of Sicilian plantations?

selbstständig verfasst habe, und dass ich keine anderen Quellen und Hilfsmittel als die angegebenen benutzt habe und dass die Stellen der Arbeit, die anderen Werken – auch elektronischen Medien – dem Wortlaut oder Sinn nach entnommen wurden, auf jeden Fall unter Angabe der Quelle als Entlehnung kenntlich gemacht worden sind.

Münster, den 12.09.23 F. [signature] Ort, Datum, Unterschrift

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