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Cécile Blanchet

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Can traits help us understanding the response of weed flora to viticultural practices?

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Defended in Rennes on the 11th of September

In front of the examinations board composed by:

President: Guenola Pérès

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Les analyses et les conclusions de ce travail d'étudiant n'engagent que la responsabilité de son auteur et non celle d'AGROCAMPUS OUEST

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Glossary

Annuals: Plant with a life cycle under 1 year which grows once a year (Chauvel et al., 2018).

AMPA: AminoMethylPhosphonic Acid (one of the primary product degradation of herbicide glyphosate).

AUREA: Laboratory of analysis and advice agro-environmental.

Community: Species gathering which occupy the same area at the same moment (Chauvel et al., 2018).

Competitor: capacity to absorb resources on fertile soil without disturbance or stress, big root system, important height and high SLA.

CWM: average trait value for a unit of biomass within a community (Kazakou et al., 2016)

ECOVITI: this network was created in 2010 by IFV (French institution of wine and vineyards). Its aim is to experiment an "organic winemaking possible economically and ecologically responsible in comparison with herbicides". For that, it tries to settle a method with low inputs at national level providing communication and training to the winegrower (Cazenave, 2017).

Ecosystem: a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit (Millennium Ecosystem, 2005).

Engrais verts (Green manure): plots lead by the chamber of Agriculture of Gironde for making test on green manure (Cazenave, 2017).

Epamprage: prick out the unfruited branches of the vines (IVF Occitanie).

Filters: Processes or constraints hindering the establishment or eliminating a species in a community (Fried and Maillet, 2018).

Functional richness (FRic): measured how the niche was occupied by the species and if it was optimally used or not (Schleuter et al., 2010).

Geophytes: Each year, decrease of the entire plant as underground part composed by the storage organ (a lot of plants with bulbs) (Navas and Garnier, 2013).

GIAF: network of plots followed since 2010 by the chamber of Agriculture of Gironde. The aim is to develop natural vegetation, try green manure practices and organic matter inputs (Cazenave, 2017).

Gradient of disturbance: the varying factor leading to a partial or total destruction of plant biomass (White and Picklett, 1985; Grime, 2001).

Gradient of resources: the varying factor is the resource needed by the plant to grow and breed as light, water, C02, minerals, etc (Navas and Garnier, 2013).

Hemicryptophytes: Regular decrease of aerial system at its basal part, consequently the future buds will be near the soil surface during the bad season (a lot of Gramineae and plants with rosettes) (Navas and Garnier, 2013).

Perennials: species which breed, live long time as vegetative way (stolon, rhizome, bulb…) (Chauvel et al., 2018).

Ruderal: species have as characteristic to acquire available resources quickly, to grow very fast and to produce numerous small seeds (Fried et al., 2019).

Specification ("cahier des charges" in French): Strict rules in organic production mode to obtain a certification.

Stress-tolerant: grow in no productive areas with small height and low SLA.

SVBA/DEPHY network: network to exchange, communicate and try technical itinerary of farmers to decrease the chemical inputs. Created in 1995 and regrouped 140 winegrowers (Cazenave, 2017).

Therophytes: plants of whom the aerial and underground systems die after seeds' production and of whom close the cycle less than a year (a lot of annual plants in cultivated areas) (Navas and Garnier, 2013).

Trait: is any morphological physical or phenological feature measurable at the individual level from the cell to the whole-organism level, without reference to environment or any level of organization (Violle et al., 2007).

Weeds: Non-cultivated plants which grow in a cultivated plot (Fried, 2019).

Abbreviations

Abun: Abundance

AIC: Akaike Information Criterion

ANOVA: Analysis of variance

CA: Correspondence Analysis

CA33: Chamber of Agriculture of Gironde (33)

CIVB: Conseil Interprofessionnel des Vins de Bordeaux

CWM: Community Weighted Mean

CWV: Community Weighted Variance

EPPO: European Plant Protection Organization

FD: Functional Divergence

FE: Functional Evenness

FR: Functional Richness

GLM: Global Linear Model

HCA: Hierarchical Cluster Analysis

IR: Inter-Rows

IQR: InterQuartile Range

IVF: French Institute of wine and Vineyards

PCA: Principal Component Analysis

PRA: small agricultural regions (Petites Regions Agricoles in French)

R: rows

S: Species richness

SHDI: Shannon's Diversity Index

SLA: Specific Leaf Area

TCA: Total Cultivated Area (Surface Agricole Utile (SAU) in French)

TFI: Treatment Frequency Index

VIF: Variation Inflation Factor

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Introduction

History of viticultural practices

The French vineyards represent a part of the French heritage since the Antiquity (Dion, 1977). Until the beginning of the twenty-one century, the French production and quality were considered as the best of the world even if all French wines do not present high quality (Phillips, 2016). Despite the improvement of wine quality in new countries such as USA, Chile, South Africa or Australia, France still has a top position in the wine world and on the market. In 2018, France is the second wine maker in Europe and in the world with 46.4 million hectoliters of wine for 755 00 hectares of production (Alim'agri, 2018).

The vine (*Vitis vinifera*) is a perennial plant grown as monoculture and need several operations during the season to manage the field, to obtain a reasonable yield and grape quality. The fungi management (mildew, powdery mildew) represents the main part of the pesticide treatments (around 16 treatments of 20.1 in Agreste, 2019). Although fewer in number, herbicide treatments (around two for herbicides and epamprage in Agreste, 2019) are pointed out in wine-growing regions because herbicides or their metabolites (e.g. AMPA) were the most commonly molecules found in water. Herbicides are used to avoid competition between weeds and vines for light and water, in order to save yield (Kazakou et al., 2016; Gaba et al., 2017) and to limit the availability of shelter for pests (Gaba et al., 2017).

The definition of weeds varies among the authors but a lot of them agree to say that a weed is an unwanted plant growing in a place managed and disturbed by humans (Baker, 1974; Randall, 1997; Radosevich at al., 2008). Eleven thousand years ago, the first farmers selected plants for their needs (the crops) keeping the others aside and considering them as weeds (Gasquez, 2018). Nowadays and in this study, we consider that weeds can be both a major problem for crop production (Radosevich et al., 2008; Kazakou et al., 2016) but also, they are tools able to provide ecosystems services as reducing soil erosion for example (Ruiz-Colmenero et al., 2013). For this study, the definition of weeds will follow the one of Fried (2019) that defines a weed as all non-cultivated plants which grow in a cultivated plot, whatever their status. Usually, several weed species grow together in the same cultivated plot and form weed communities whose composition and diversity are determined by abiotic and biotic filters. Filters are processes or constraints hindering the establishment or eliminating a species in a community (Fried and Maillet, 2018). The weeds can be associated to ecological strategies based on the competition (C), the stress (S) and disturbance (D) according to Grime (Grime, 1974). Grime's CSR strategies are usually used to compare flora in cultivated areas and to describe weeds communities (Gaba et al., 2014, Kazakou et al., 2016; Fried et al., 2019).

To control the potential adverse effects of weeds, tillage was usually applied on the vineyards before the 1970's to weed the rows and the inter-rows (Barralis et al, 1983; Maillet, 1992). From the 1970s the first authorized vine herbicides were put on the market.

Chemical weeding was gradually adopted, first located on the rows, maintaining superficial tillage on the inter-rows, then carried out "in full" (rows plus inter-rows) with complete abandonment of all soil tillage operations (Maillet, 1992). These changes of management practices lead to major evolutions on weed communities. Tillage or herbicides have selected certain types of weeds called ruderal according to the Grime's theory (Grime, 1988). These ruderal species are prone to acquire available resources quickly (between two disturbances events), to grow very fast and to produce numerous small seeds (Fried et al., 2019). The combination of no-tillage and herbicides in vineyards allows the colonization of vines by perennial plants, even woody species, whose deeps roots are difficult to reach even with herbicides (Montégut, 1982).

The massive use of herbicides has also provoked a huge decline of species diversity as well as a decrease of the abundance per species (Barralis, 1983) and can have unintended effect on other species than the target ones (Fried and Maillet, 2018). Moreover, the herbicides are responsible for water pollution (Martínez et al., 2000; Louchart et al., 2001) and it becomes a priority to reduce them. Nowadays, this challenge is taken into account by the government with the decrease of the number of actives molecules retired from the market (from 21 in 2001 to 11 in 2012, Gaviglio, 2013). Moreover, more and more vineyards adopted an organic management (in 10 years, the number of organic vineyards has tripled and in 2016 it represents 9% of the total number) increasing the use of tillage in the inter-rows (Agence Bio/OC, 2017).

A new challenge: reducing inputs to take advantage of the ecosystem services

Many ecosystem services can be provided by the weed communities if they are well managed. First of all, the competition between the weeds and the wine grape decreases the strength of the vines improving the grape quality (increasing the alcohol content, diminution of acidity…) (Van Leeuwen and Seguin, 1994; Pellegrino et al., 2005) and decreases the vineyards works as epamprage, thinning out of leaves or clipping and improves the microclimate, which decreases the fungal diseases. Secondly, the weeds can provide trophic resources, shelters, wintering and reproduction areas for pollinators, granivore arthropods, herbivorous and omnivorous, birds and mammals (Bàrberi et al., 2010), better pest regulation by favoring the crop auxiliaries as earthworms or *Carabidae* (balance between pests and crop auxiliary), pollination services (sexed reproduction, biofuel production or medicines with vegetal origins) and grains (Kazakou et al., 2018). The earthworms and the dynamics of microorganisms present in the soil can increase the quality of the soil allowing the minerals' retention (less nitrogen lixiviation and more carbon sequestration). A better soil increases the water service during the winter period and improves the water's quality. For all these reasons, there is an important tendency in vineyards to leave a certain amount of vegetation in the vines. This vegetation includes weed species that are spontaneous (Boisson, 2016) and sometimes also a cover crop which consist of one or several chosen species deliberately sown by winegrowers (Metay et al. 2018).

These cover crop constitute a service crop (Garcia et al., 2018). They can be temporary sown, as barley (left in winter and terminated in spring), or permanent, such as tall fescue (Celette et al., 2010). They are mainly sown in the inter-rows (less in the rows to avoid competition) but with different pattern, i.e. sometimes every inter-row, one inter-row over two, one inter-row over three, etc (Metay et al., 2018). The management of the rows and of the inter-rows is often different because of the proximity of vines in the rows and the width of the inter-rows which allow the use of mechanical tools (Metay et al., 2018). Alternative physical tools exist to regulate the weeds such as mowing, mechanical and thermic weeding, mulch and more traditional practices such as the crushing of wine branches, the rolling or the grazing (Metay et al., 2018). However, studies about the effects of these alternative practices remain scarce and do not allow to advise winegrowers properly on how to manage weeds in both the spontaneous cover or cover crop situations.

Using a trait-based approach to explain and predict relationships between management practices and weed communities

Classical studies on the ecology of weed communities have tried to link management practices to a given species composition (Barralis et al, 1983; Gago et al, 2007). This taxonomic approach shows some limits which can be partially overtaken by the functional approach. This latter approach is inspired by the functions performed by the plants and the role of species in the ecosystems. The concept was born in the 19th century with Von Humbolt (1806) in Grime and Pierce (2012) but was only developed during the 20th century and has been widely used by the ecologists for 20 years. As the functions of species are hard to reach and measure, proxies, called traits, are used to obtain information on these functions. The term “traits” has been widely used with various meanings. Violle et al (2007) proposed a definition that is widely agreed upon: “a trait is any morphological physical or phenological feature measurable at the individual level from the cell to the whole-organism level, without reference to environment or any level of organization”. That means nothing around the species traits, environmental factors nor population is necessary to *describe* the traits (of course, when measuring the trait values, it remains important to characterize the environment). The main interest of using the traits is to generalize the links between the practices and the flora.

In comparison to cultivated fields with annual crops where the concept was largely applied (Fried et al., 2009; Gunton et al., 2011; Fried et al., 2012), the vineyard appear as an ideal model to improve our understanding of weed responses to various types of disturbances thanks to a higher diversity of management practices applied in vineyards over the last decades (Gago et al., 2007). The present study takes place in the Bordeaux Wine Region and is part of the VERTIGO project (supported by the CIVB) following the thesis of Lorelei Cazenave (2017). The aim here is to characterize the response traits of weeds to viticultural practices. Thus, questions occur in accordance to this aim:

- (1) What are the different weed strategies (combination of traits) beyond the diversity of weeds in vineyards?
- (2) To what extent can these strategies be related to the contrasted management practices in the rows and in the inter-rows and to the environmental gradient (soil, weather, landscape)? i.e. are rows and inter-rows harbouring different weed communities?
- (3) Do the management practices in vineyards (tillage, mowing, herbicides, fertilization) act as filters on plant traits? What are the main traits that respond to different gradients of management practices?
- (4) Finally, from a methodological point of view, we asked what is the best strategy for analyzing the influence of management practices on weeds between: i) the use of broad but integrative classification as organic versus conventional mode of production, ii) the use of 'cropping systems' identified as homogeneous groups of vineyards plots using similar practices, iii) the use of the raw management practices variables?

To answer these questions, the weed communities will be analyzed to understand their composition and their functioning thanks to the Grime's strategies (Grime, 1988). Then, the impacts of management practices and other environmental variables will be studied through the three levels of analyses (see the question #4) on the weeds' diversity and on the trait's values.

Hypotheses

(1) It exits different ecological strategies which can be based on the reproduction, the adaptation, the resources or the functional traits. The Grime's CSR strategies will be used to answer the question of weed strategies. The first hypothesis is that as in all cultivated area, the flora in vineyards is essentially composed by ruderal species because of the high level of disturbances. One the other hand, the vineyard can be managed with a diversity of practices. For example, herbicides can be applied only in the rows and mowing only in the inter-rows (Metay et al., 2018). Different management practices can also be applied on the same area (rows or inter-rows) at different period, such as mowing followed by tillage (MacLaren et al., 2019). Therefore, the second hypothesis is that with this diversity of practices through time and space the weeds communities will adopt different strategies.

(2) Studies showed that season and latitude (location of the plots) can be the main filters to weeds communities (Fried et al., 2019), whereas others studies showed that the main impact on weed communities are management practices (Lososovà et al., 2002; Kazakou et al., 2016). The first hypothesis is that the abiotic filters as weather, soil properties and landscape will shape the weed communities and as they are similar on the same plot, the rows and the inter-rows weed communities will be identical whatever the practices.

The second hypothesis is that different management practices in the rows and in the inter-rows will translate on the fields by different communities in the both areas for diversity and traits.

(3) The practices applied on vineyards act as filters on plant traits (Lososovà et al., 2003; Kazakou et al., 2016; Gaba et al., 2017; MacLaren et al., 2019). Even Fried et al. (2019) showed a tiny impact of management practices after the season and the latitude influence on weed communities.

The first hypothesis concerns the influence of management practices on weed communities' diversity. The hypothesis 1.A. is that the practices will impact the taxonomic and the functional diversity by direct (herbicides) and indirect effects (soil compaction through the number of mechanical passages) (Hole et al., 2005; Bruggisser et al., 2010). The hypothesis 1.B. is that the practices are not responsible for the difference of diversity between production mode (Nascimbene et al., 2012).

The second hypothesis concerns the combination of traits found under different gradients of disturbance. The hypothesis 2.A. is that a high gradient of disturbance will favor traits values associated to ruderal strategy with high SLA, small height and low seed mass (Grime, 1988), with early flowering onset (Garnier et al., 2016), as under mechanical passages. At the opposite, the trait values in low disturbed areas will follow competitive strategy (gradient of resources) with high maximum height, high SLA and small seeds (Kazakou et al., 2016). High disturbance can be associated to the use of pesticides which can be associated to a low level of pollinators. So, the self-pollination and dispersal can be expected in this context (Fried, 2019). Besides, the higher is the disturbance, the more we expect a convergence of the traits (especially for tillage) whereas the lower is the disturbance, as for mowing, the more we expect a divergence of traits (Kazakou et al., 2016).The hypothesis 2.B. is that weeds will have other traits as the traits of ruderal strategy to overpass the management practices (Garnier et al., 2016). The traits will be a low SLA (to invest in the plant structure, less permeability to herbicides) and a high seed mass under tillage management to be able to emerge from deeper in soil and to be able to grow (Armengot et al., 2016). The maximum height will increase to acquire light faster under disturbed areas (MacLaren et al., 2019).

(4) Three approaches concerning the description of management practices will be applied. The first hypothesis is that the three approaches will be complementary and at each level the information will be more accurate. The second hypothesis is that the organic/conventional approach will not be enough accurate (MacLaren et al. (2019) used three levels of production mode), the raw variables at the opposite will give many information but hard to interpret, whereas the groups will be a good trade-off between the two other approaches.

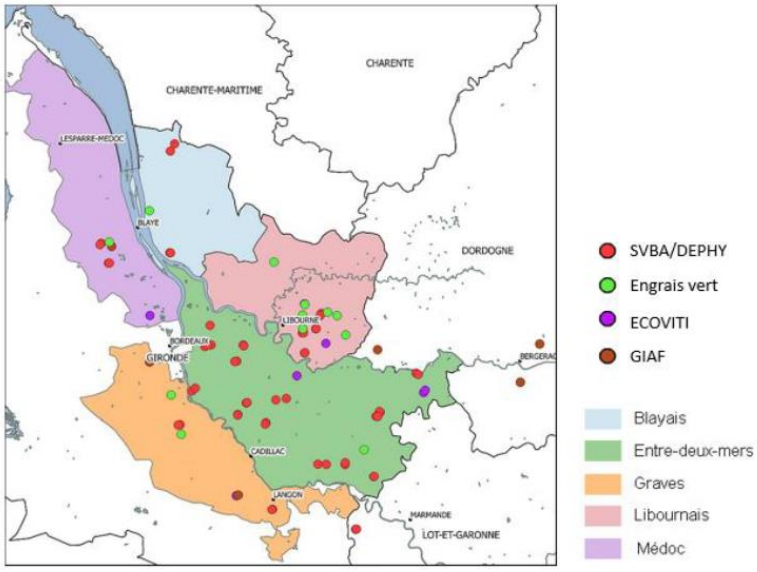

Figure 1: Location of the 101 plots of vineyards (Cazenave, 2017)

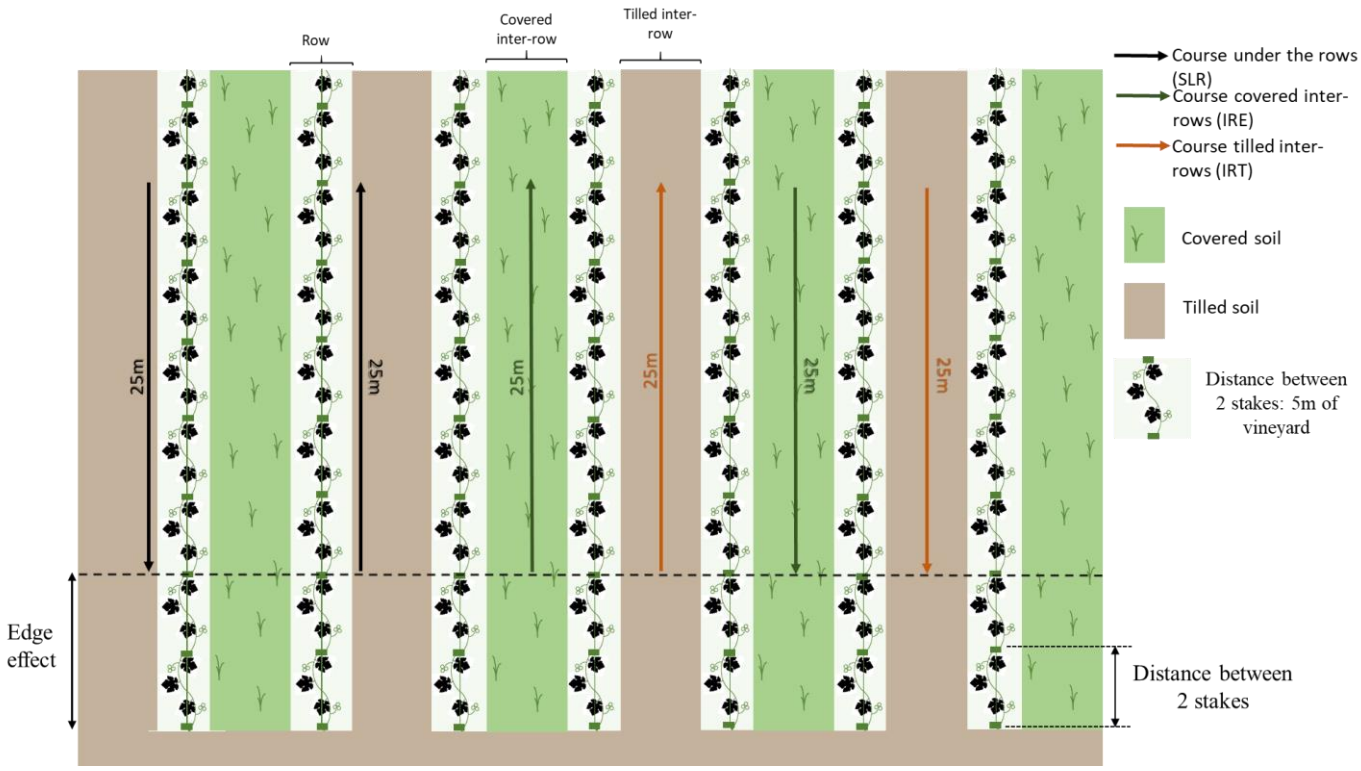

Figure 2: Scheme describing the method to provide the floristic sampling of each plot (took back from Varela (2015))

Material and methods

I. Data acquisition

I.1. Vegetation survey

All the floristic surveys were done in 2015 in the Bordeaux vineyards (Cazenave, 2017). This wine production region gets an oceanic climate and has vineyards growing on the sand, graves and silt-calcareous soil (Vin & vigne, 2015). Nowadays in Aquitaine, 50 % of the total cultivated area (TCA) produces wine grapes (Agreste, 2015). With the ECOPHYTO plan, which aims to reduce by 50 % the herbicides use until 2025 (Plan ECOPHYTO II, 2015), and the cover crop success in the Bordeaux, the chemical weeding is limited under the rows only (Agreste, 2019). Moreover, the treatment frequency index (TFI) of herbicides reaches 0.7 as the national mean (Agreste, 2019). One hundred and one101 plots belonging to 51 vineyards distributed in the Gironde (98 plots), the Dordogne (2 plots) and the Lot-et-Garonne (1 plot) departments were studied. The plots belong to five networks: GIAF (2x6 plots), ECOVITI (2x7 plots), Engrais Verts (2x12 plots), DEPHY/SVBA (52 plots) (defined in the glossary). One of the plots has been tilled before the floristic sampling (101 plots instead of 102). Figure 1 showed the distribution of the vineyards and their belonging to networks and to the small agricultural regions (*Petites Regions Agricoles (PRA)* in French).

A vineyard plot can be divided into three types of area: the rows, the tilled inter-rows and the covered inter-rows (spontaneous or sowed vegetation (i.e. cover crop)). The floristic sampling protocol developed by the Chamber of Agriculture of Gironde (CA33) (Varela, 2015) considers this heterogeneity. For each area (rows, tilled and covered inter-rows), the sampling method was to record all species over 50 m length (2 x 25 m, around 10 vineyard stakes) with a width of 1 m, that corresponded to a total of 150 m²/plot (Figure 2). The rows (R) and the inter-rows (IR) were randomly chosen as the beginning zone for the sampling. The only rule was to avoid the edge effect, so it had to begin after 2 stakes from the edge. For the plots where the inter-rows were only tilled, the sampling was performed on two inter-rows to obtain the same surface per plot.

For each species, the frequency and the abundance were noted. Frequency was based on the presence/absence of the species on 10 sections of 5 m with a resulting frequency ranging between 1 (one individual) and 5 (species present in all the sections) (Cazenave, 2017) (Table 1). Abundance was obtained thanks to the cover percentage of each species per plot. The method comes from Braun Blanquet et al. (1934) which describes the abundance with 5 categories going from 1 for the isolated species (cover <5%) to 5 for species forming a continuous carpet (cover > 75%) (Table 2). To end, frequency and abundance were multiplied to obtain the percentage of cover of each species per plot. The species were identified in the database with their scientific, common and EPPO names (http://eppt.eppo.org/).

Table 1: Evaluation table of frequency inspired by Theau et al. (2010)

Class	Frequency
1	Single individual
2	Rare species
3	Observed species every 4-6 stakes
4	Observed species every 2-3 stakes
5	Observed species every stake

Table 2: Evaluation table of abundance according to Braun-Blanquet (1934)

Class	Covering	Mean density (D2)
1	Species covering 1% to 5%	0.025
2	Species covering 5% to 25%	0.15
3	Species covering 25% to 50%	0.375
4	Species covering 50% to 75%	0.625
5	Species covering 75% to 100%	0.875

Table 3: Description of climate variables

Climatic variables	**Definition**	**Mean – sd**	**Min – Max**
Rainfall (mm/year)	Average on the year 2015	674.50 ± 46.32	593.68 – 848.52
Temperature average (°C/year)		12.45 ± 1.23	10.32 – 14.10
Evapotranspiration (mm/day)		2.67 ± 0.08	2.47 – 2.89

Table 4: Description of the soil properties

Abbreviations	**Definition**	**Unit**	**Mean – sd**	**Min – Max**
Pl_A	Clay percentage	%	19.04 ± 10.79	2.7 – 54.9
Pl_L	Silt percentage	%	33.35 ± 17.37	5.1 – 70.7
Pl_S	Sand percentage	%	47.81 ± 23.51	3.0 – 87.2
Pl_$CaCO_3$	Calcareous content in the soil	g/kg of soil	34.15 ± 71.60	0.0 – 271.0
Pl_MO	Organic matter content in the soil	g/kg of soil	1.82 ± 0.81	0.4 – 4.58
PD_CN	Carbon/Nitrogen ratio	No unit	10.28 ± 2.57	4.0 – 17.4
PD_PH_EAU	pH measured with water	No unit	7.49 ± 0.99	5.3 – 12.7
PD_PH_KCl	pH measured with KCl	No unit	6.33 ± 0.91	4.1 – 7.9
PD_CEC	Cation exchange capacity	mol/kg of soil	9.13 ± 4.85	2.8 – 24.8
PD_P_2O_5	P_2O_5 content	g/kg	0.095 ± 0.090	0.01 – 0.451
PD_K_20	K_20 content	g/kg	4.01 ± 37.76	0.043 – 374
PD_MgO	MgO content	g/kg	0.24 ± 0.16	0.042 – 0.82

Table 5: Description of the selected landscape variables

Abbreviations	**Definition**	**Unit**	**Mean – Sd**	**Min – Max**
Surf	Surface of the plot	Square meter (m²)	7776 ± 4905	784.1 – 24580
Slope	Angle of the slope	degree (°)	2.61 ± 1.75	0.307 – 9.07
V_20 m	Vineyards 20 m radius	%	50.97 ± 17.06	5.45 – 84.33
V_100 m	Vineyards 100 m radius	%	77.26 ± 17.32	29.42 – 100

The floristic sampling was made twice: the first one at the end of Marsh/ beginning of April before the first treatment (herbicides, tillage, mowing) were applied in the plot; and the second one at the end of June/beginning of July after that all management practices have been applied (tillage, herbicides treatment, mowing). In total, 541 floristic samples were made in 2015, containing 200 species of weeds. Because of the yearly alternation between tilled and covered inter-rows, the distinction between those two kinds of inter-rows was not relevant and when a plot contained tilled and covered inter-rows, the maximum of the density (D2) was taken. At the end, 400 floristic samples were describing the rows, the inter-rows and the sampling period (winter and summer). The table containing the maximum of density (D2) for each plot was named the matrix L.

I.2. Environmental variables

I.2.1 Climate

A partnership with the French Institute of Wine and Vineyards (IVF) allowed obtaining the climatic data for each plot, thanks to the TRYDEA tool. It gave the mean temperature, the mean rainfall and the mean potential evapotranspiration (Table 3) for each plot every day of the year 2015.

I.2.2 Soil properties

Soil was sampled at two depths: 0-30 cm and 30-60 cm, using an auger. On each plot: 6 auger samples were taken on 2 inter-rows of the vineyards and 6 others on 2 rows of the vineyards. The choice of the inter-rows and the rows were made randomly avoiding the edges of the plot. The analyses were performed by the AUREA laboratory based in Blanquefort (Gironde) (Table 4).

I.2.3 Landscape and topography

Landscape data can help understanding how the land cover around the studied plots influences weed community composition or diversity in the vineyards. The landscape database has been obtained in a previous study (Boisson, 2016) thanks to the ArcGis® software 10.1 and its extension 'spatial analyst', produced by the ESRI firm. To characterize the landscape, the proportion of each habitat types (urban zones, annual crops, perennial crops, water areas, grasslands, vineyards, forests and woodlands, as well as a miscellaneous category) was determined. Shannon's Diversity Index (SHDI) was then calculated based on the number and relative proportion of the different habitat types, to represent landscape heterogeneity. Land cover and SHDI were computed for several buffer sizes: 50 m, 100 m, 250 m and 500 m radius around the plot. After running GLMs to explain weed species richness according to landscape diversity with different radius sizes, Boisson (2016) suggested to use the landscape metrics based on the 100 m radius according to the best model selected by the Akaike Information Criterion (AIC). The 100 m buffer size was considered as a good spatial scale to capture the percentage of vineyards and landscape diversity around the vineyard plots (Boisson, 2016). Moreover, the 20 m radius landscape was also kept because it represented the nature of the habitat at the edge of the plot, i.e. the most likely habitat to send plant propagules in the vineyard.

Table 6: Description of the agricultural practices

Abbreviations	Definition	Unit	Mean – Sd	Min - Max
feng	Chemical fertilization	Number of fertilizations over the last 5 years (scale from 0 to 5)	2.13 ± 0.16	0 – 5
famo	Organic soil improver, return organic matter from the vine shoot and green manure.	Number of fertilizations over the 5 last years (Famo = Fam + Rmo, Fam: scale from 0 to 5 for the organic soil improver and Rmo: scale 0 to 10 for the vine shoot and green manure restitution)	6.46 ± 2.41	0 – 13
nherb	Herbicides which can be selective or not. They were applied on the rows only but can also have an impact on the inter-rows.	Number of herbicides passage per year	0.88 ± 1.05	0 - 3
wir	Tillage in the inter-rows	Number of passages per year x the number of inter-rows of the plot/2	1.77 ± 1.75	0 - 8
wsr	Tillage in the rows	Number of passages per year	2.21 ± 2.36	0 – 8
ntont_ir	Mowing in the inter-rows	Number of mowing per year x the number of inter-rows/2	3.50 ± 1.89	0 – 7
ntont_sr	Mowing in the rows	Number of mowing per year	0.62 ± 1.40	0 - 5
npm	Number of mechanical passages	Number of passages per year	26.7 ± 5.42	15 – 40

Table 7: Description of qualitative traits

Biological type	Meaning	Number	Justification
T	Therophytes	98	Biological types reflect the variation of responses to stress and disturbances, established by Raunkiaer in 1934. The therophytes die after the seed production, the geophytes had an organ into the ground and the hemicryptophytes lose the aerial part (Navas and Garnier, 2013).
Hsto	Hemicryptophytes with stolon	21	
Heri	Erected hemicryptophytes	18	
Hros	Hemicryptophytes with rosettes	16	
Hces	Tussock hemicryptophytes	9	
Gbul	Geophytes with bulbs	12	
Grhi	Geophytes with rhizomes	11	
Bis	Biannual	9	
W	Woody plants	6	
Pollination mode	**Meaning**	**Number**	**Justification**
Anemogamous	Pollination by wind	42	Capacity of the plants to reproduce alone (auto-apogamous), with abiotic factors (wind) or thanks to biotic factors (insects). For this last case, the hypothesis can be that the entomogamous plants were more sensitive to the decrease of pollinators then to intensive management practices. It is also the only traits which give links with others organisms.
Auto-apogamous	Self and asexual pollination	23	
Optional entomogamous	Different ways of pollination including insects	69	
Compulsory entomogamous	Pollination with insects only	66	
Dispersal	**Meaning**	**Number**	**Justification**
Animals	Eaten or attached on animals	72	Colonisation capacity and relation with the seed mass and the reproductive height (Gaba et al, 2017).
Gravity and self	Felt on the floor or dispersed by the plant itself	76	
Wind	Brought by the wind	52	

Angaud (2018) performed a PCA on the landscape variables composed by SHDI and the different habitat types at 20 m and 100 m radii. She showed that the vineyard 100 m radius contributed the most to the construction of the axes and was positively correlated with the vineyard 20 m radius and the surface of the vineyard plot (m^2) and was negatively correlated to SHDI. Therefore, we decided to summarize landscape variables by the percentage of vineyard that informed if the landscape around the studied plot was homogeneous or not, so if there was a source of diversity around.

The surface of the vineyard plot was also recorded. Previous studies have shown that there is a negative correlation between the size of the agricultural plots and the level of biodiversity (Fried et al., 2018). This correlation can be related to increase management intensity with higher field size or to a landscape configurational effect due to less field margin vegetation in landscape with large field size.

We also considered a topographic variable with the slope. The slope can have an influence on the species composition (Perring (1959) in Bennie et al., 2006) and can influence the magnitude of vegetation change (Bennie et al., 2006). Moreover, the slope influences also the practices: for example, the mechanical engines were difficult to handle in steep vineyard plots, so there are fewer tillage in this kind of plots while chemical control or spontaneous or cover crop are more often used to avoid the soil erosion (Vrsic et al., 2011). The surface, the slope, the proportion of vineyard in the 20 m and the 100 m radii were described in Table 5.

I.3. Agricultural practices

The management practices applied in the vineyard plots were gathered thanks to an electronic interview (google forms) of the concerned winegrowers. Based on a literature review (Gago, 2007), the main practices to consider for their effect on weed flora were: soil tillage (with the difference between rows and inter-rows), mowing (with differentiation between the rows and the inter-rows), and herbicides treatments, fertilizations (chemical or organic) and the total number of mechanized treatments (including diseases treatments, harvest…) (Table 6). This latter variable is the sum of the number of tractors passes which could be an indirect measure of soil compaction. The table containing all the environmental variables as climate, soil properties, landscape and agricultural practices was named the matrix R.

I.4. Plant traits

Different traits and ecological performance indicators were used in this study. These two types of indicators came from the data base BIOFLOR (Klotz et al., 2002) and baseflor (Julve, 1998). There were qualitative traits (Table 7) including the biological types, the pollination and the dispersal modes. There also were quantitative traits (Table 8) including the functional traits and the Ellenberg's indicators, which characterize the response of species to environmental factors (Ellenberg et al., 1992). Ellenberg (1992) has listed these 6 indicators which were adapted to the central Europe conditions and Julve (1998) adapted it for the French vegetation. The matrix containing the traits was named the matrix Q (traits in columns and species in rows).

Table 8: Description of quantitative traits and ecological performance indicators (Units given by Bourgeois et al., 2019)

Traits	Definition	Unit	Mean ± Sd	Min – Max	Justification
SLA_final	Ratio between the leaf area and the leaf mass	$m^2.kg^{-1}$	25.49 ± 7.21	5.55 – 53.24	Responds to competition for light, to nitrogen inputs and indicates the investment in plant function (PS) (Gaba et al., 2017).
Max_height_FG	Maximum height at maturity	m	0.91 ± 2.11	0.1 – 30	Responds to dispersal mode, to competition for light, to nitrogen input and to insect pollination (Gaba et al., 2017).
Seed mass final	Seed mass	g	3.04 ± 10.18	0.0095 – 120	Reflects the competitive ability of seedlings. Responds to seed predation, dispersal distance and emergence depth (Gaba et al., 2017).
Flowon	Month of flowering onset	month	4.20 ± 1.57	1 – 8	Responds to timing of disturbance events (harvest and agricultural practices) and avoid competition for light by early flowering onset.
Flowdur	Number of months for flowering duration	month	5.13 ± 2.23	2 – 12	Responds to disturbance events and change (harvest and agricultural practices) of diversity (Gaba et al. 2017) by being able to flower several times.
Light (L)	Response to light	-	7.22 ± 0.96	3 – 9	Tolerance to shade (Hill et al., 1999) Ellenberg L can discriminate weed response to competition (Gaba et al., 2017).
Temperature (T)	Response to temperature	-	5.71 ± 0.96	4 – 8	Tolerance to coldness.
Continentality (C)	Response to temperature in summer and in winter	-	4.41 ± 0.86	2 – 8	Tolerance to continental climates (dry in summer, cold in winter).
Soil_humidity (F)	Response to moisture of the soil	-	4.98 ± 1.34	2 – 9	Tolerance to dryness (Hill et al., 1999).
pH (R)	Response to soil richness (acid or basic soil)	-	7.55 ± 1.17	2 – 8	Tolerance to acidity (Hill et al., 1999).
Trophic level (N)	Response to nutrients contents in the soil	-	5.78 ± 1.59	1 – 9	Tolerance to soil infertility (Hill et al., 1999). Ellenberg N can reflect the plant growth to soil nitrogen availability (Gaba et al., 2017).

In this study, the analyses are performed on a complete dataset. As the missing data represented less than 5% of the total dataset (2.6% (73/2800) for the matrix Q and 0.5% (16/3232) for the matric R), they were filled with predictive mean matching using the mice package. In order to avoid outliers, the seed mass and the plant height were log-transformed.

All the data were coming from the thesis or Lorelei Cazenave and some precisions were added thanks to Tristan Boisson for the landscape metrics and Maude Angaud for the number of variables. The addition and treatment of the plant trait data and the choice of the relevant variables for each analysis were the topic of this internship.

II. Data analyses

II.1. Characterization of weed communities

II.1.1 Weed community diversity

Each plot was first characterized by species richness (S), given the number of different species in a plot and the total abundance, the sum of abundance of all species in the plot. Then a number of indices were computed in order to describe the functional diversity and structure of the communities. Many studies showed that the species diversity was not enough to describe the ecosystem and that the functional diversity was needed to better understand their functioning (Tilman et al., 1997, Hulot et al., 2000, Díaz and Cabido, 2001, Heemsbergen et al., 2004 in Schleuter et al., 2010). The functional diversity can be defined by 3 types of indicators which are functional richness (FR), functional evenness (FE) and functional divergence (FD) (Schleuter et al., 2010), which are considered as independent in a random community. The first indicator taken is the functional richness (Fric), which measured how the niche was occupied by the species and if it was optimally used or not (Schleuter et al., 2010). The index used for this functional richness was coming from the hull volume of Cornwell et al. (2006) (Mason et al., 2013). The second indicator is the functional divergence represented by the Rao's quadratic entropy. Rao's quadratic entropy gave the distance of traits between a pair of species and was a very used index for its flexibility (Schleuter et al., 2010). It represented a generalization of the Simpson index and can be calculated with the following formula (Leps et al. 2006):

$$FD(Rao) = \sum_{i=1}^{S}\sum_{j=1}^{S} dij.pi.pj$$

with S, the total number of species in the community, p_i and p_j, respectively the proportion of the species i and j, d_{ij} the dissimilarity between the species i and j. dii = 0 because there was no dissimilarity in the same species. If d_{ij} = 1, the pair of species was totally different, and another formula was used (Botta-Dukàt 2005):

$$FD(Rao) = 1 - \sum_{i=1}^{S} pi^2$$

The species richness and the abundance give information on the number of plants in the niche and the quantity of each of them. The functional indicators which are the functional richness (FRic) and the Rao's quadratic entropic (Rao) bring more information on the functional side of the study with the comparison with an optimum thanks to FRic and a distance between the traits thanks to the Rao's index. The Gower's distance calculated for these two indicators allowed to compute distances for qualitative variables as the biological type and non-continuous variables as the Ellenberg indicators (c.f. I.4 Plant traits) (Karadimou et al., 2016). So, the four indicators were supplementary and described from different angle the diversity of the plots. The dbFD function returns FRic and Rao indicators per plot (Laliberté and Legendre, 2010).

II.1.2 Weed community functional structure and composition

The community weighted mean (CWM) and the community weighted variance (CWV) were calculated for each trait. CWM could be computed thanks to the dbFD() function, which took into account the relative abundance of species per each plot. The CWM values "represent the average of traits values for a unit of biomass inside a community" (Kazakou et al., 2016). For the qualitative traits, it gave the percentage of presence of each trait in each plot. The CWV was calculated for each plot only for the quantitative traits by this formula (Hulshof et al., 2013; Bestovà et al., 2018):

$$CWV = \sum_{i=1}^{S} Ai \times (ti - CWM)^2$$

where A_i was the abundance of species i, and t_i is the trait value of species i.

II.2. Characterization of management practices through environmental conditions

We chose to describe management practices by using an increasing level of complexity:

i) First of all, we used a very raw but consistent and integrative classification of plots based on the production mode followed by the winegrowers: organic versus conventional farming.

ii) The second strategy for analysing the data was to identify homogeneous groups of plots based on similar management practices. This is based on the idea that beyond organic and conventional production mode, there can be differences (e.g., one can assume that there are different types of organic farming and different levels of intensity within conventional winegrowers). First, the table with the 101 plots described by the eight management variables were subjected to a Principal Component Analysis (PCA) followed by a Hierarchical Cluster Analysis (HCA). Four groups were identified using the optimal number of clusters given by Mantel statistic, which compared the original distance matrix and the binary matrices computed from the dendrogram cut at various levels (Borcard et al., 2011). The management practices that best discriminates the four groups were identified thanks to the test value (v_test), which calculated the gap between the global mean and the mean of a modality and allowed the groups' description (catdes (FactoMineR) Husson et al., 2016).

iii) In the last strategy, we tested directly the influence of all the 14 raw management practices variables including the soil, the landscape and the climate on weed species (functional) diversity and composition.

II.3 Statistical analysis

II.3.1 Analysis of weed functional strategies

A Hill & Smith analysis was performed on the matrix Q (200 species x 14 traits). A Hill & Smith analysis is equivalent to a Principal Component Analysis (PCA) adapted to matrixes mixing qualitative and quantitative variables (Hill and Smith, 1976). The Grime categories competitors, stress-tolerant and ruderal (Grime, 1974) were added as supplementary variables. They allowed to understand the repartition of the species categories depending on the traits and see if it corresponded to the strategies described by Grime. Then a Kruskal Wallis test was applied followed by a Dunn test to understand the distribution of Grime strategies along the first axes.

On the same matrix Q, the fidelity index to the inter-rows was calculated to determinate the species that are specific to each area (rows and inter-rows) and then linked to the traits. This index was calculated from the Chytrý et al. (2002) formula:

$$\varphi = \frac{N.\mathrm{np} - n.Np}{\sqrt{n.Np.(N-n).(N-Np)}}$$

with N the number of samples used (400 floristic samples), Np, the number of samples in the inter-rows (201 floristic samples), n, the number of occurrences of the species in the whole dataset and np, the number of occurrences of the species in the inter-rows. This index ranged from -1 (species associated to the rows) and 1 (species associated to the inter-rows) (Fried et al., 2019).

II.3.2. Influence of environmental variables on weed community diversity and on weed community composition

i) Linear models with interaction applied to the three methods

The statistics were performed on the three methods level: the production mode (conventional versus organic), the groups practices and the raw variables and the aim was to compare the influence of each method and of the area (rows/inter-rows) on the diversity (taxonomic: S, Abundance; functional: FRic, Rao) and on the traits (CWM and CWV). To obtain such analyses, linear models with interaction were performed on the 400 floristic samples. An ANOVA (type III) was applied to emphasize the significance of the diversity's indicators and the traits' values (CWM and CWV). For the production mode, the model significance was tested thanks to the glht function from the multcomp package (Tukey test). For the groups, the model significance was evaluated thanks to the testInteraction function from the phia package. And for the raw variables, the model was selected thanks to the Akaike Information Criterion (AIC). The AIC is an estimator of an expected distance developed by Kullback and Leibler (1951) which represents the loss of information between the reality and the model.

The aim was to maximize resemblance to the reality with the less variables as possible. The model chosen will be the one with the smallest AIC (Posada and Buckley, 2004). Then, the Shapiro test was applied on all linear models to verify the normality of the residuals of the ANOVA. The test was passed if the null hypothesis is accepted (p_value above 0.05). However, the dataset contained 400 floristic samples and Shapiro did not always work, so the normality was also evaluated on traits' histograms (Appendix III). The variation inflation factor (VIF) was also applied to evaluate the collinearity into the model, if VIF value exceeded 10, the variables were removed from the models. A predictability of the model (repartition of the fitted results along the first bisector) was operated to assure the veracity of the model. The CWM of all biological types except therophytes, the flowering duration, the auto-apogamous and the facultative entomogamous and all CWV were sqrt-transformed to follow a normal distribution.

ii) Complementary approach and relationship between the environmental variables and the traits: RLQ – fourth corner analyses

Dray et al. (2014) developed an approach combining two analyses to show significant relationship between the traits and the environmental variables. For that purpose, a RLQ analysis was performed on the three matrices, the floristic matrix L, the traits matrix Q and the environmental matrix R. It is similar to a multivariate analysis which identify the best viewing of the "cloud's points". The RLQ displayed axes that best discriminates species (based on their traits) and sites (based on their environmental characteristics) and maximizes the covariance between environmental variables and the traits. It was the first step to have an idea of the correlation between the traits and the practices. Before the RLQ analysis, preliminary statistics were applied on each matrix. First, a Correspondence Analysis (CA) was performed on the floristic matrix L after a square-root-transformation on the matrix. This analysis was used as a canonical factor for the following analyses. Secondly, a Hill & Smith was performed on the traits' matrix Q, which was scaled with the columns scores of the CA of the matrix L. Thirdly, a PCA was performed on the environmental matrix R, which was scaled with the rows scores of CA of the matrix L.

One of the drawbacks of the RLQ analysis is that it does not allow to make a direct correlation between the environment variables and a single trait. So, a second analysis was performed which is called the fourth-corner analysis. It realized simultaneously statistical tests on bivariate associations (one trait and one environment variable at a time). 9 999 permutations were made to adjust the p-value and the threshold of the significance was set at $\alpha = 0.05$. However, this analysis does not consider the combinations of practices on one hand and the combinations of the traits on the other hand. So, the two analyses (RLQ and fourth corner) were combined to avoid their inconvenient when they are used separately.

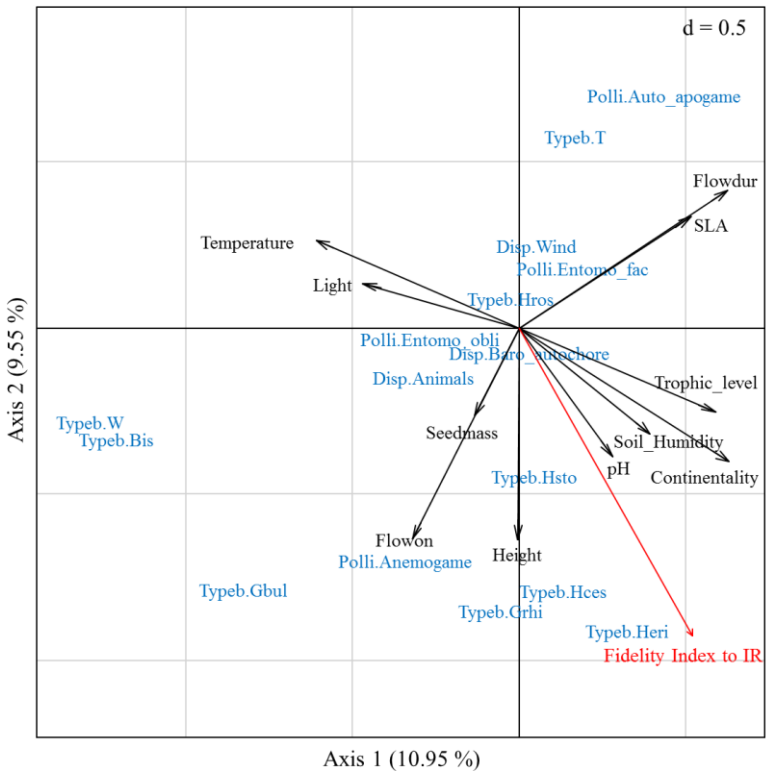

Figure 3: Hill & Smith analysis displayed with the quantitative variables in black marked out by an arrow, the qualitative variables in blue and the supplementary variable: Fidelity Index in the inter-rows in red marked out by an arrow.

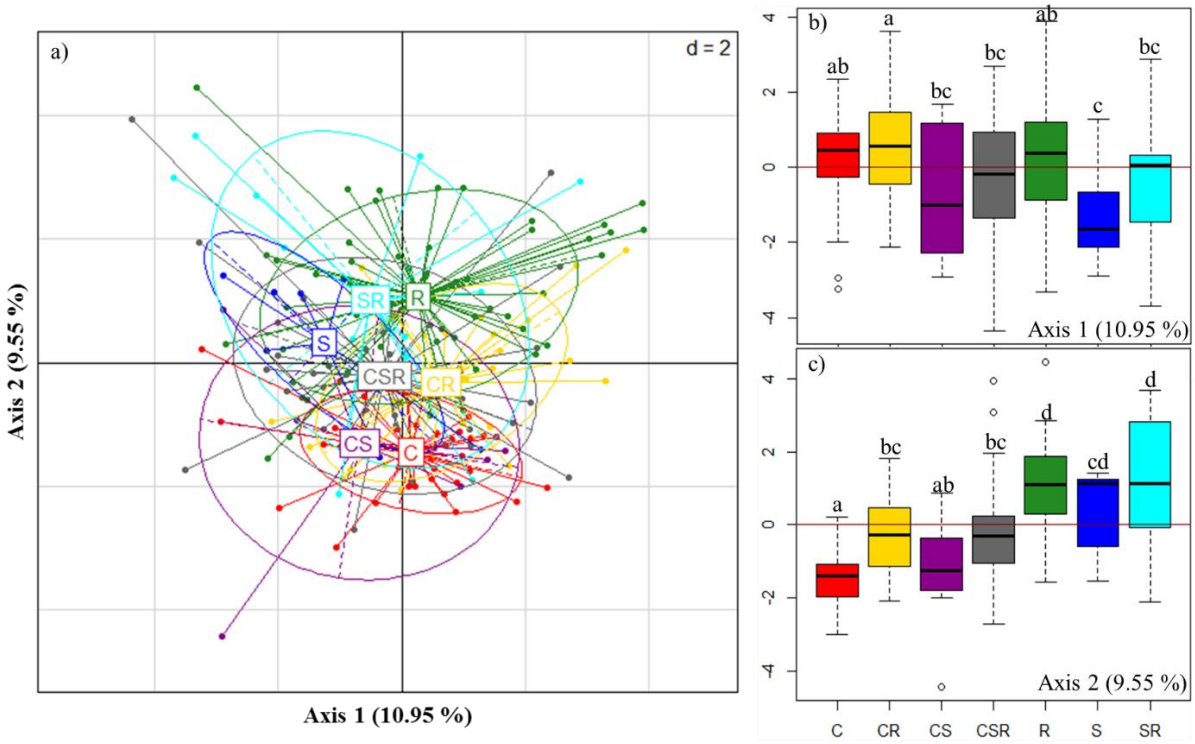

Figure 4: Grime strategies as supplementary variables on the Hill & Smith analysis (a), C: Competitor, S: Stress-tolerant and R: Ruderal, and the significance of the distribution along the 1st axis (b) and the 2nd axis (c) of the multivariate analysis

This combination of analyses allowed highlighting the significant correlation between the combinations of environmental practices and each trait, and the significant correlation between the combinations of traits and each management practice.

This approach was also implemented separately on the rows and on the inter-rows, and on the winter and the summer sampling periods, using the 400 floristic samples to test the influence of the areas (rows/inter-rows) and the sampling period (summer/winter), which were not considered in the global analysis performed on the 101 plots gathering the two sampling periods.

All the statistics ran thanks to the ade4, car, FactoMineR, FD, MASS, multcomp, phia and vegan packages and ggplot2 package displayed the figures.

Results

I. Analysis of weed functional strategies (Grime's strategies)

I.1. Axes of specialization of vineyards weeds

The aim of this Hill & Smith analysis was to highlight suites of traits associated to the fidelity of weeds to the IR and to interpret them in the light of the Grime strategies. We kept the first four axes of the Hill & Smith analysis which explained 35.86 % of the traits' distribution (Figure 3, see the inertia table in Appendix II and contribution of the variable to the axes). The first axis was positively correlated with Ellenberg's indicators for continentality (39.7 % of relative contribution to the construction of the axis 1) and for trophic level (34.6 %), flowering duration (39.2 %) and SLA (26.6 %). The first axis was negatively correlated with Ellenberg's indicators for temperature (-37.1 %) and for light (-21.8 %). The second axis was positively correlated with therophytes (32.2 %) and negatively with maximum of plant height (-40.4 %) and flowering onset (-40.3 %). This second axis also opposed annual species (therophytes) to perennial species (various types of geophytes and hemicryptophytes).

I.2. Vineyards weed functional traits related to Grime's strategies

The Grime strategies describe three types of species, the ruderals, the stress-tolerant and the competitors, and the combinations between the three types of species. The Figure 4.a) showed the belonging of each species to a Grime's strategy according to species position in the trait multivariate space (Figure 3). It occurred a similarity between this graph and the Grime's triangular model (1974) explaining the strategies with the combination CSR at the center, the C, S and R shaping a triangle around the center and between two strategies, the combination of both was found. According to the Figure 4.b), the first axis opposed the ruderal and the competitor strategies (C, CR and R) to the stress-tolerant strategies. The second axis clearly opposed the ruderal strategy to the competitor strategy (Figure 4.c)). Linking the strategies to the traits (Figure 3), the ruderal strategy was correlated with low seed mass, low maximum height and early flowering onset.

Table 9: Species with high fidelity index to the inter-rows (green on the left), fidelity index close to zero (orange in the middle) and high fidelity index to the rows (red on the right)

Species	Fidelity Index IR	Species	Fidelity Index IR	Species	Fidelity Index IR
RUMCR	0,43605	CIRER	0,01840	EHIVU	-0,02306
PLALA	0,41808	MATIN	0,01840	CVPSA	-0,02598
TRFRE	0,40354	ARBTH	0,01823	VICHI	-0,02816
TAROF	0,38106	SILGA	0,01610	LACSE	-0,03019
AGSST	0,33830	CARHI	0,01220	VLLLO	-0,03079
HOLLA	0,33427	SETVI	0,01217	MIPMI	-0,03315
DACGL	0,33397	EQUSS	0,01134	ALLCE	-0,05031
FESAR	0,32914	RUMAA	0,01086	ARISE	-0,05031
BELPE	0,31836	RAPRA	0,00950	GASCI	-0,05031
LOLPE	0,30874	LAMPU	0,00209	SEDAC	-0,05031
HRYRA	0,30152	ALGHI	-0,00035	SONAR	-0,05031
BROMO	0,29910	CERFO	-0,00035	MERAN	-0,05076
PLAMA	0,26502	TOINO	-0,00035	TROPR	-0,05076
LOTCO	0,24740	TULSS	-0,00035	OROPE	-0,05133
IUNEF	0,24577	EPIHI	-0,00050	LAMAM	-0,05205
ERICA	0,23066	HIEPI	-0,00050	SETPU	-0,05293
LOLMU	0,23003	LUUCA	-0,00050	EPHCY	-0,07124
RANBU	0,21412	TOIJA	-0,00050	AMADE	-0,08736
FESOV	0,21002	KICSP	-0,00062	RBIPE	-0,08736
RUMAC	0,20794	LTHTU	-0,00062	SENVU	-0,09041
PICEC	0,20329	OXAEU	-0,00062	HEEHE	-0,09789
PRUVU	0,20151	SXFTR	-0,00062		

Table 10: The F_value, the estimate and the significance concerning the habitat, the production mode and the interaction between both, for the species richness, the abundance, the functional richness (FRic) and the Rao's quadratic richness. The points (.) indicated a p_value above 0.05, the stars indicated a p_value between 0.05 and 0.01 with a star (*), a p_value between 0.01 and 0.001 with two stars (**) and a p_value under 0.001 with three stars (***). The adjusted R^2 indicated the contribution of the model to the diversity's indicators.

Diversity	R^2 (adjusted)	Area	Production mode	Interaction
Species richness	0.37	**162.8/-11.5 *****	1.68/1.34	3.06/2.57 .
Abundance	0.36	**127.3/-2.30 *****	**17.5/0.98 *****	1.56/0.41
FRic	0.17	**50.99/-0.025 *****	2.65/0.0066	0.09/0.0018
Rao's index	0.14	**54.87/-0.005 *****	0.42/-0.0005	3.0/0.0019 .

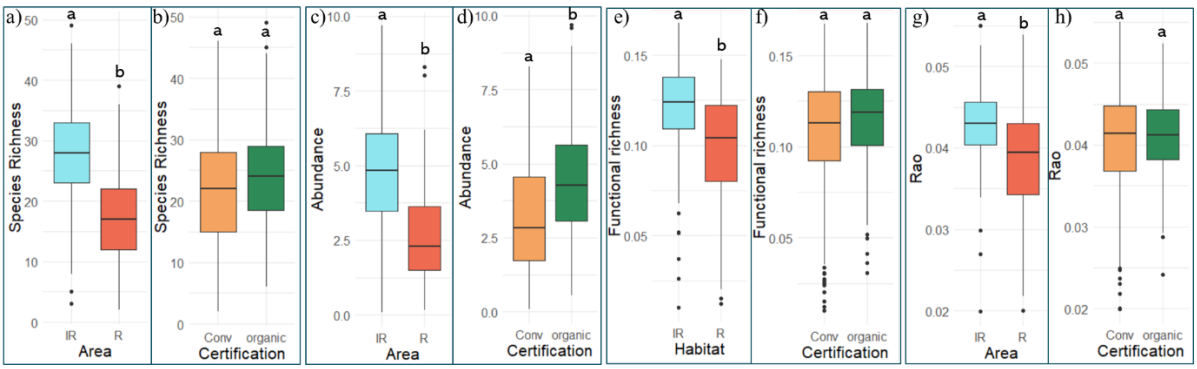

Figure 5: Diversity's indices, i.e. the species richness (a,b), the abundance (c,d), the functional richness (e,f) and the Rao's quadratic entropy (g,h), according to the area (inter-rows in blue, rows in red), the mode of production called here certification (conventional in orange and organic in green). The horizontal bar of the boxplot represents the median, 50% of the values were located from the 1st quartile to the 3rd quartile (interquartile range, IQR). Blacks dots are values higher or lower than 1.5 the IQR.

The competitors were positively correlated with maximum height, hemicryptophytes (tussock and erected), soil properties and climatic conditions (continentality, trophic level, pH and soil moisture). The stress tolerant species were positively correlated with Ellenberg's indicators for temperature and for light and negatively to Ellenberg's indicators for trophic level and for soil moisture.

I.3. Describing the fidelity index to the inter-row by the traits' variables

The index of fidelity to the inter-rows (IR) ranged from -0.098 for *Hedera helix* (the species with the highest fidelity to the rows (R)) to 0.44 for the *Rumex crispus* (the species with the highest fidelity to the IR). Table 9 list the fidelity scores for the more frequent plants based on the presence/absence data. It seemed that there were more species with high fidelity to the IR than species with high fidelity to the R. The species with a high fidelity to the IR were all hemicryptophytes, mainly anemogamous and entomogamous, heliophilous and nitrophilous. The species with high fidelity to the R, which are treated chemically by herbicides, were mainly split in two categories. The first one counted small annuals with short life cycle until March/April and the second one, the woody species like *Hedera helix* possessing deep roots and waxy leaves giving natural tolerance to herbicides sprays.

The fidelity index to the IR was significantly linked to Ellenberg's indicators for temperature (cor = -0.16, P = 0.03) and for soil moisture (cor = 0.27, P = 0.0001), axis 2 (cor = -0.15, P = 0.03) and axis 3 (cor = -0.24, P = 0.0008). Based on the trait that contributed the most to axes 2 and 3 (Figure 2, Appendix II), this analysis highlight that the fidelity index to the IR was positively correlated with traits' combination: high maximum height, high seed mass, late flowering onset and various perennials life forms (geophytes with rhizomes, erected and tussock hemicryptophytes, opposed to therophytes), short flowering duration and low SLA. Based on Grime's strategies, the fidelity index to the IR was positively linked to competitors and negatively to ruderals.

II. Influence of environment on weed community (functional) diversity

II.1. Effect of conventional and organic production mode

This part aimed to understand if there was an influence of production mode (organic vs conventional), of the areas (R/IR) and/or their interaction on the weed community diversity. The abundance was the only diversity index showing a significant difference between the production modes (Table 10) with a higher score for organic one (Figure 5). The four diversity indices showed a significant difference between the areas (Table 10) with a higher score for the IR (Figure 5).

II.2. Effect of management practices

In this part, the aim was to test if a classification of vineyard plots into groups with similar management practices can more accurately explain weed community diversity. Based on the three first axes of the PCA (representing 67.8% of the total variability of the practices' matrix), the Hierarchical Cluster Analysis and the Mantel statistic, we were able to distinguish four groups of plots (Appendix III).

Table 11: F_value of linear models with interaction of the diversity's indices. The point (.) indicated a p_value above 0.05, the stars indicated a p_value between 0.05 and 0.01 with one star (*), a p_value between 0.01 and 0.001 with two stars (**) and a p_value under 0.001 with three stars (***).

Diversity's indices	Area (rows/inter-rows)	Group	Interaction
Species richness	18.1 ***	12.4 ***	10.2 ***
Abundance	14.9 ***	8.5 ***	5.6 ***
FRic	4.0 *	7.6 ***	4.2 **
Rao	8.7 **	3.6 *	4.6 **

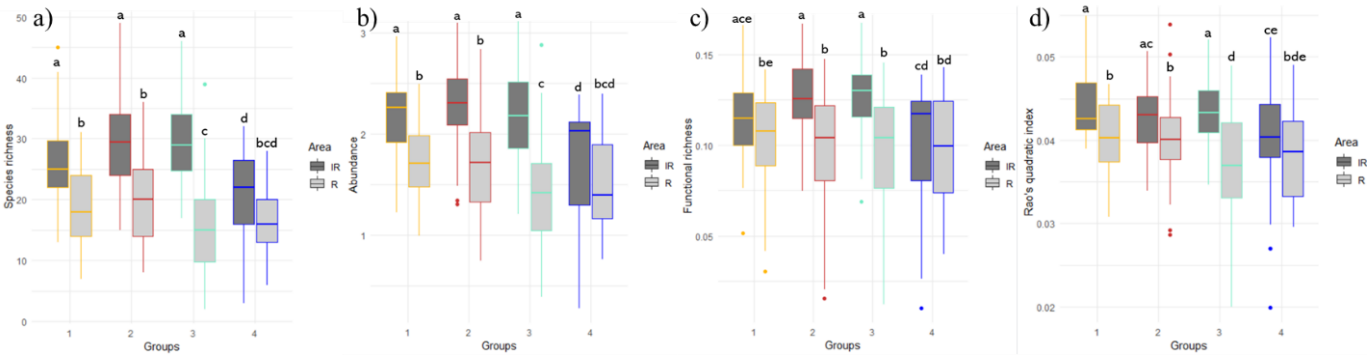

Figure 6: Boxplots of the repartition of the four groups depending on the diversity's indices: Species richness (a), Abundance (b), Functional richness (c) and Rao's quadratic entropy (d). The inter-rows were represented in dark grey and the rows in pale grey, the group 1 is in yellow, the group 2 in red, the group 3 in green and the group 4 in blue.

Table 12: Linear models given the F_value and the estimate for the four indices of diversity: species richness (S), abundance (Abun), functional richness (FRic) and the Rao's quadratic entropy (Rao). A compartment in color is significant, green for the positive interactions and yellow for the negative ones. The point (.) indicated a p_value above 0.05, the stars indicated a p_value between 0.05 and 0.01 with one star (*), a p_value between 0.01 and 0.001 with two stars (**) and a p_value under 0.001 with three stars (***).

Traits/ Var	Date Winter	Area R	V_100 m	Sand	MO	CN	pH	feng	famo	nherb	wir	wsr	Nton t_ir	Ntont_ sr	npm	Rainfall
S	85.2 5.9 ***	278.6 -10.6 ***	2.6 -0.54	10.9 -1.1 **					3.6 0.65 .	12.5 -1.3 ***	8.6 -1.2 **			10.4 -1.2 **	9.3 1.02 **	
Abun	28.4 0.2 ***	213.1 -0.6 ***	14.9 -0.08 ***	5.9 -0.06 *	10.0 0.08 **	2.2 0.04			15.3 0.08 ***	40.0 -0.2 ***	7.6 -0.08 **		2.1 0.04	8.3 -0.07 **	7.5 0.06 **	
FRic	90.9 0.02 ***	98.7 -0.03 ***							5.5 0.003 *		16.8 -0.006 ***			4.3 -0.003 *	5.1 0.003 *	2.3 -0.002
Rao	107.5 0.005 ***	93.0 -0.004 ***	10.5 -0.001 **	16.1 -0.001 ***		9.5 0.001 **	9.0 -0.001 **		7.1 0.001 **		8.6 -0.001 **	10.7 -0.001 **			3.1 -0.0004 .	

The first group (in yellow) represented plots where mowing was applied in both the R and the IR, where organic manure was used and where there was a high number of mechanical passages. The group 2 (in red) represented plots where winegrowers implemented tillage in the R, mowing in the IR and who used organic manure. The group 3 (in green) represented plots where winegrowers implemented herbicides in the R, mowing in the IR and who used chemical fertilization. The group 4 (in blue) represented plots where winegrowers implemented tillage in the R and in the IR with high number of mechanical passages.

The four diversity indices showed a significant difference between the areas, the groups and their interaction (Table 11). The species richness and the abundance showed the same results (Figures 6a and 6b), with a higher the species richness and the abundance in the IR in comparison with the R except for the group 4 (tillage in both R and IR) which presented similar results between both areas.

For the IR, species richness and abundance were significantly lower in the group 4 compared to groups 1, 2 and 3 while there were no significant differences between these three latter groups. For R, species richness and abundance were higher for groups 1 and 2 compared to groups 3 and 4. Functional richness (FRic) was higher for the IR than for the R in groups 2 and 3 while there was no significant difference between the R and the IR for groups 1 and 4 (Figure 6c). Groups 1, 2 and 3 had a higher FRic than group 4 for the R but no difference was found between the groups for the IR. The Rao's quadratic entropy was higher in the IR than in the R except for the group 4, which presented no significant difference (Figure 6d). In the IR, groups 1, 2 and 3 had no significant but groups 1 and 3 showed a higher Rao's quadratic entropy than the group 4. In the R, there was no significant difference between the groups.

II.3. Relationship between the traits and the environmental variables

The aim of this part was to test the effect of each management practices and their relative influence compared to climatic, soil and landscape variables. After performing a PCA (Appendix IV) with the environmental variables, 14 variables were kept: the vineyard percentage at 100 m radius (V_100 m), the sand percentage (Sand), the organic matter (MO), the C/N ratio (CN), the pH, the rainfall and the eight the management practices: mowing in the R (ntont_sr), mowing in the IR (ntont_ir), tillage in the R (wsr), tillage in the IR (wir), organic manure (famo), chemical fertilization (feng) and number of mechanical passages (npm). Table 12 displayed the results of linear models using the 14 variables to explain variations in species richness, abundance, functional richness and Rao's quadratic entropy. The four indices were significantly higher during the winter period than during the summer period. The indices were also positively correlated with the use of organic manure (except the species richness) and the number of mechanical passages (except for the Rao's index). The four indices were significantly lower in the R compared to the IR, and they were negatively correlated with the number of tillage in the IR, the number of mowings in the R (except for the Rao's index) and sand percentage (except for FRic).

Besides, the number of herbicides treatments was only negatively correlated with species richness and abundance but not to functional diversity's indices. The proportion of vineyard in the landscape was negatively correlated with abundance and Rao's index. The Rao's index was negatively correlated with pH and the number of tillage in the R and positively correlated with the C/N ratio.

III. Influence of environmental variables on weed community functional composition

In this part, some traits were discarded from the modelling process; the Shapiro tests and the visual inspections of histograms of traits indicated that the residuals of the models for the CWM of biannual, geophytes with bulbs and rhizomes, erected hemicryptophytes and woody species did not follow a normal distribution. Moreover, concerning the Ellenberg's indicators, only the one for trophic level was kept because the other were hardly interpretable.

III.1. Effects of conventional and organic production mode

The CWM of traits showed a significant difference between the areas (R/IR) with a higher score in the IR for the CWM of hemicryptophytes (tussock, rosettes, stolons), flowering onset, anemogamous and animal dispersal; and a higher score in the R for the CWM of therophytes, SLA, flowering duration, auto-apogamous, facultative entomogamous, wind dispersal and Ellenberg's indicator for trophic level. The CWM of traits also showed a difference between the production mode (organic/conventional) with a higher score in organic farming for the CWM of hemicryptophytes (tussock, stolons) and anemogamous; and a higher score in conventional farming for the CWM of therophytes, facultative entomogamous, wind dispersal and Ellenberg's indicator for trophic level. The CWV (variance) of all traits were higher in the IR and in organic production mode (Appendix V).

III.2. Effects of management practices

The CWM of traits showed a significant difference between the areas for the group 3 only (except for the tussock hemicryptophytes which showed a significant difference in the 4 groups and the hemicryptophytes with rosettes in the groups 1 and 3), with a higher CWM in the IR of hemicryptophytes with stolons, flowering onset, facultative entomogamous and animal dispersal; and a higher CWM in the R of therophytes, SLA, flowering duration and Ellenberg's indicator for trophic level. The CWM of traits showed a significant difference between the groups in the IR, especially for the group 4, with a higher CWM of therophytes and facultative entomogamous and a lower score for the CWM of hemicryptophytes (tussock, rosettes, stolons) and animal dispersal. There was also a significant difference in the R between the groups 1 and 2 and the groups 3 and 4, with a higher score for CWM of hemicryptophytes with stolons and maximum height in the groups 1 and 2; and with a higher score for the CWM of the therophytes and flowering duration in the groups 3 and 4. The CWV of all traits were higher in the IR for the groups 1, 2 and 3. In the IR, the group 4 had lower CWV than the other groups and in the R, the group 3 has lower CWV than the groups 1 and 2 and sometimes 4 (Appendix VI).

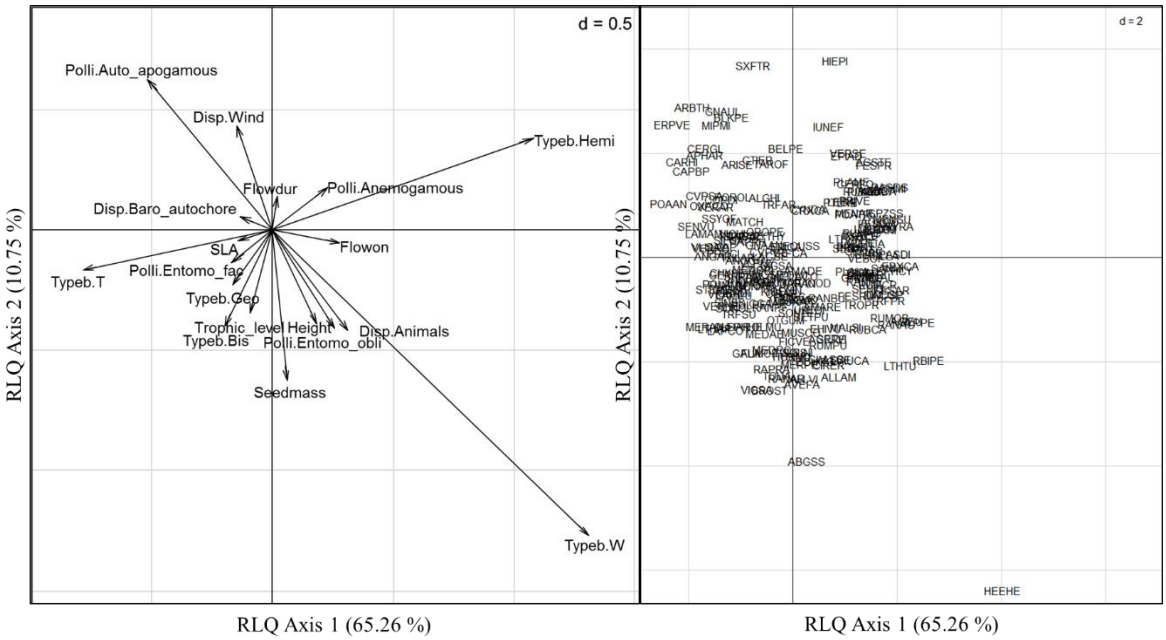

Figure 7: Results of the global RLQ (101 fields) for the traits (on the left) and the species (on the right)

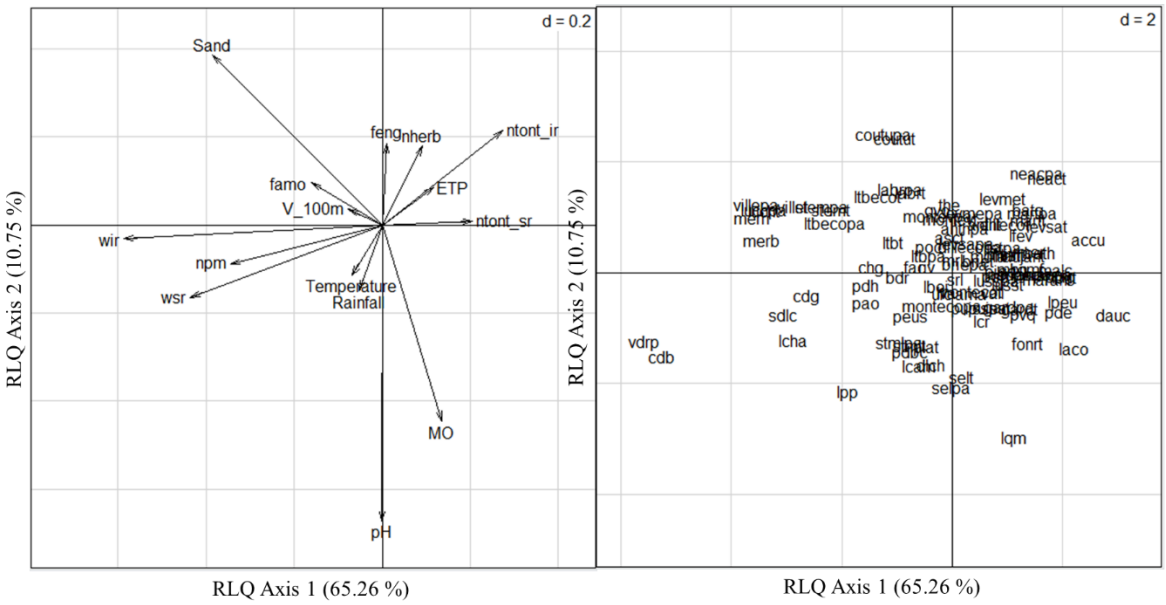

Figure 8: Results of the global RLQ (101 fields) for the environment variables (on the left) and the field (on the right)

III.3. Relationships between traits and environmental variables (climate, soil properties, landscape) and management practices

III.3.1. RLQ and fourth corner analyses

The first two axes of the RLQ accounted for 81.31% of the total inertia (65.26% and 10.75% for the RLQ axes 1 and 2, respectively). The first axis of the RLQ discriminated the species (Figure 7) according to the biological type. The hemicryptophytes were positively correlated to the axis 1 and opposed to the therophytes. The SLA was linked to the therophytes as well as to the geophytes and to an early flowering onset. The second axis of the RLQ discriminated the species according to traits related to competitive ability (seed mass, plant height, trophic level) and to the mode of dispersal and pollination. The axis 2 was positively correlated with the wind dispersal, the wind-pollinated species, auto-apogamous species and flowering duration. At the opposite, the axis 2 was negatively correlated with the seed mass and the maximum height, entomogamous (obligate outcrossing plant species that depend on insect pollinators), the trophic level and animal-dispersed species. The woody biologic type contained few species and could be considered as an outlier (with the *Hedera helix*). Its position on the positive loadings of Axis 1 together with other perennials (hemicryptophytes) is however consistent.

The axes of the RLQ separated the practices (Figure 8) on the first axis and the environmental variables on the second axis. The first axis of the RLQ was positively correlated with the number of mowing in the R and in the IR and the evapotranspiration. On the other side, the first axis of the RLQ was negatively correlated with the number of soil tillage in the R and in the IR, the total number of mechanical passages, the vineyard percentage and the organic manure. The second axis of the RLQ was positively correlated with the chemical fertilization, the number of herbicide treatments and sand percentage. The second axis was negatively correlated with the pH, the organic matter, the temperature and the rainfall. Appendix VII displayed the RLQ performed separately on the R and on the IR. The season was the principal contributor to the axes' construction for both areas. The summer sampling period was positively correlated with the first axis as same as the flowering onset, the anemogamous, the woody plants and the maximum height, the rainfall, the mowing in the R and in the IR for the IR only and the organic matter for the IR only. At the opposite along the first axis, the winter sampling period was positively correlated with the flowering duration, the SLA and the auto-apogamous for the traits and the sand for the R and the IR. The combination between the traits and the environmental variables were still almost the same as the global RLQ.

The fourth corner analysis showed 14 significant correlations (over 270 possible ones) between environmental variables and traits (Figure 9). The hemicryptophytes were positively correlated with the mowing in the IR ($r = 0.083$, $P_{adj} = 0.0054$) and negatively with the sand percentage ($r = -0.092$, $P_{adj} = 0.006$), the tillage in the R ($r = -0.12$, $P_{adj} = 0.0054$) and in the IR ($r = -0.14$, $P_{adj} = 0.0054$) and the number of mechanical passages ($r = -0.078$, $P_{adj} = 0.006$).

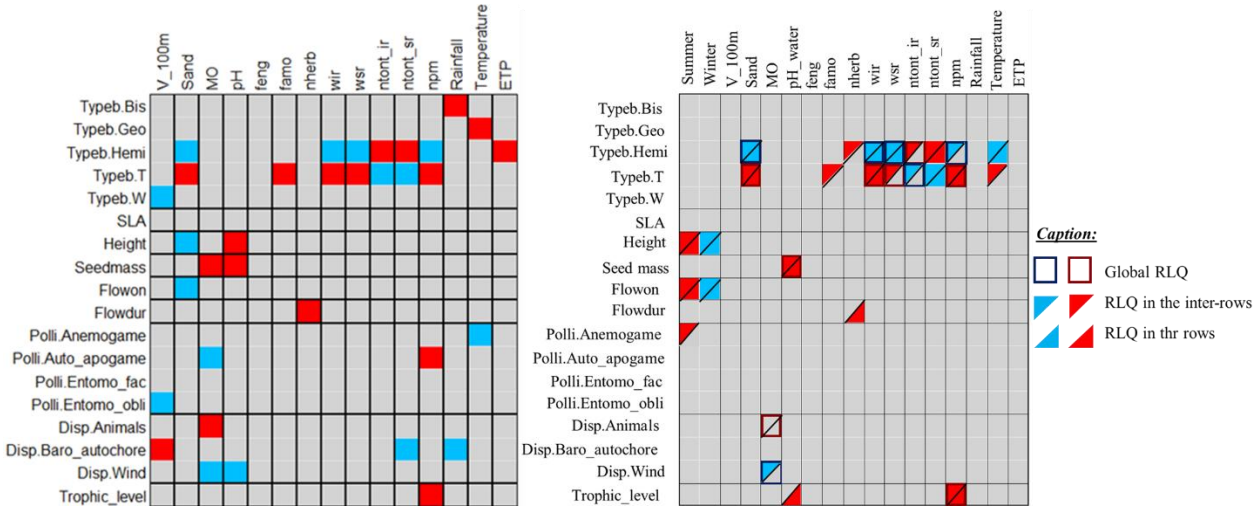

Figure 9: Fourth corner analysis of the global dataset (101 fields) on the left and adjusted fourth corner analyses of the three datasets (global, rows, inter-rows) on the right. The red cells represented the positive associations and the blue cells represented the negative associations. The non-significant cells were represented in grey. The upper left triangles represent the inter-rows significant interaction, the bottom right triangles the rows and the empty squares the global interaction.

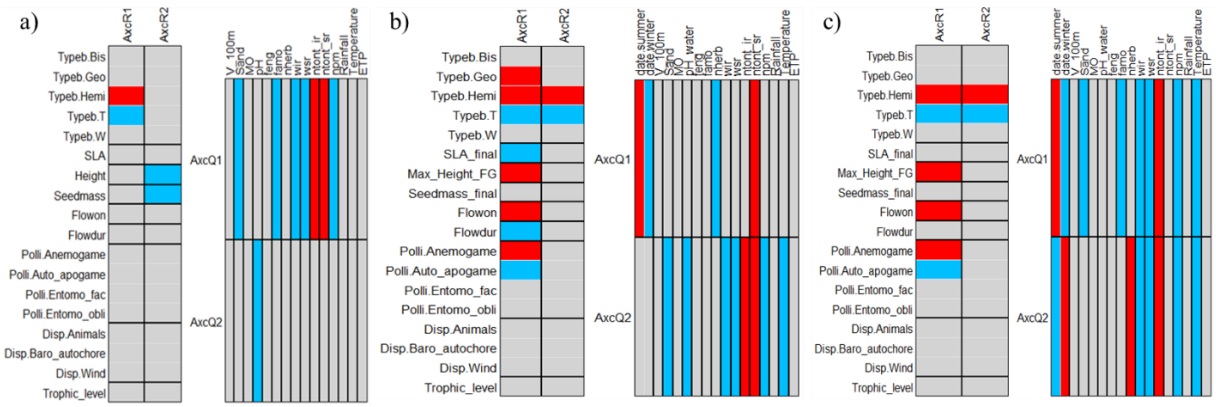

Figure 10: Results of the combination of the RLQ and the fourth-corner analyses for the global (a), the rows (b) and the inter-rows (c) analyses. On the left of each table, the fourth-corner tests between the two axes of the RLQ for the environmental gradients and the practices (AxcR1/AxcR2) and traits. On the right of each table, fourth-corner tests between the two axes of RLQ for traits (AxcQ1/AxcQ2) and the environmental variables and the practices.

The therophytes showed the opposite combination with a positive correlation with the percentage of sand (r = 0.079, P_{adj} = 0.012), the number of tillage in the R (r = 0.10, P_{adj} = 0.006) and in the IR (r = 0.14, P_{adj} = 0.0054) and the number of mechanical passages (r = 0.073, P_{adj} = 0.006) and a negative correlation with the number of mowing in the IR (r = - 0.075, P_{adj} = 0.0054). The level of soil organic matter was positively correlated with the animal dispersal (r = 0.042, P_{adj} = 0.037) and negatively correlated with the wind dispersal (r = -0.043, P_{adj} = 0.048). The seed mass was positively correlated with the pH (r = 0.063, P_{adj} = 0.020), which represented rich soil mainly calcareous. To end, the number of mechanical passages was positively correlated with the trophic level (r = 0.065, P_{adj} = 0.0081). The fourth corner analyses in the R and in the IR showed a positive correlation between the summer sampling period, the maximum height, the flowering onset and anemogamous pollination and a negative correlation between the winter and these traits. The results of the IR and the R fourth corner analyses for the other traits were very similar to the global one. Additional results were interesting as the positive correlation between the flowering duration and the number of herbicides treatments (cor = 1.0, P_{adj} = 0.004) for the R.

For the RLQ and 4th corner combination, the first axis was positively associated with the hemicryptophytes and the number of mowing in the R and in the IR (Figure 10a.). On the other hand, the axis 1 was negatively associated with the therophytes, the sand percentage, the organic manure, the number of tillage in the R and in the IR, the number of mechanical passages and the temperature average. The second axis of the RLQ was negatively associated with the seed mass, the maximum plant height and the soil pH. That meant the richer was the soil, the bigger was the seed and the higher was the stem. For R/IR combinations (Figures 10 b and c), more traits were associated but the correlation between the height, the seed mass and the pH did not occur. Both of these analyses combined the hemicryptophytes, the maximum height, the flowering onset, the anemogamous, the summer sampling period, the number of mowing in the R (for the R) and the number of mowing in the IR (for the IR). These traits were opposed to the therophytes, the SLA, the flowering duration and the auto-apogamous, the winter sampling period and the number of herbicides for the R and opposed to the therophytes, the auto-apogamous, the winter sampling period, the sand percentage, the organic manure, the tillage in the R and in the IR, the number of mechanical passages and the temperature for the IR.

Unlike the global combination, the second combination of R and IR combinations took back the opposition between the hemicryptophytes and the therophytes. For the R, the combination opposed the hemicryptophytes, the number of mowing in the R and in the IR on one side and the therophytes, the sand percentage, the pH, the number of tillage in the R and the IR, the number of mechanical passages and the temperature on the other side. For the IR, the combination opposed the hemicryptophytes, the winter sampling period, the number of herbicides, the number of mowing in the R and in the IR on one side and the therophytes, the summer period, the number of tillage in the R and in the IR, the number of mechanical passages and the temperature on the other side.

To summarize, the first axis described the practices along a soil disturbance gradient which split the species according to their biological type with therophytes being associated to soil tillage and the hemicryptophytes being associated to mowing.

Whereas the second axis reflected a soil resource gradient related to soil pH, discriminating species according to their seed mass, with species with a low seed mass found on low soil pH and species with a high seed mass found on high soil pH.

III.3.2. Linear models' results

The linear models' results showed similar results as the RLQ – fourth corner analyses (III.3.1), with a detailed description in Appendix VIII, with correlation between the management practices, the sand percentage and the temperature; and the biological type (therophytes and hemicryptophytes) showing a opposite combination. The positive correlation between the pH and the seed mass also occurs in these results, as well as the positive correlation between the flowering duration and the number of herbicide treatments. Moreover, some information can be added to the RLQ – fourth corner analyses. The organic manure has a positive correlation with CWM of traits (hemicryptophytes, therophytes, seed mass, facultative entomogamous, baro-autochory and animal dispersal), whereas the chemical fertilization has a negative correlation with CWM of traits (compulsory entomogamous and animal dispersal). There was no correlation with the mowing in the inter-rows.

The CWV of traits showed a positive correlation with the winter sampling period, the inter-rows, the organic matter and manure and the number of mechanical passages and a negative correlation with summer sampling period, the rows, the vineyard and sand percentages, the number of herbicide treatment, tillage in the inter-rows and mowing in the rows.

Discussion

I. CSR strategies of Grime suited to weed communities in Bordeaux vineyards

The question was to describe the weeds communities present in the Bordeaux vineyards and to know if weeds strategies were identifiable. Plotting Grime's strategies showed that a first axis of differentiation of weeds of vineyards can be interpreted as a resource gradient, opposing stress-tolerant species to ruderal and competitive species while a second axis of differentiation can be interpreted as a disturbance gradient opposing ruderal strategies to competitive strategies. That confirms the second hypothesis assuming the occurrence of different Grime's strategies among vineyard weeds instead of ruderal species only.

It is striking that the ordination of weed flora of vineyard based on a selection of few traits suit so well with Grime's triangular model. Especially since the traits used here do not fully cover those used by Hodgson et al. (1999) (canopy height, dry matter content, flowering period, flowering start, lateral spread, leaf dry weight, SLA) or Pierce et al. (2017) (SLA, Leaf Dry Matter Content, Leaf Area).

Based on the selected traits, ruderal weeds can be defined as annual plants with a short stature, a high SLA, an early flowering onset and a long flowering duration. Weeds with a competitor strategy are hemicryptophytes with a high stature and high seed mass. The stress tolerant weeds are heliophilous and thermophilous species, resistant to drought and temperature variations (continentality). Compared to weeds of annual crops (wheat, maize) where weed communities are more skewed toward ruderal weeds (Gaba et al., 2017), it is also interesting to note that weeds of vineyards cover more evenly all the different CSR strategies. This can be explained by a higher diversity of management practices (tillage, herbicides, mowing) in the different vineyards and within a same vineyard plot (row versus inter-rows).

Consistently, the projection of the fidelity index to the inter-rows on the multivariate space of weed species trait was correlated to a disturbance gradient opposing ruderal species on the rows and competitive species on the inter-rows. Interestingly, no single traits explained well the fidelity index to the inter-rows indicating that the species belonging to the inter-rows are better characterized by a combination of traits (high height, important seed mass, late flowering onset, small SLA, short flowering duration and various life forms as geophytes with rhizomes, erected and tussock hemicryptophytes, but not therophytes). As the rows and the inter-rows have different types of disturbances and that some microclimate can exist (Metay et al., 2018), the difference of weeds communities can be understood. However, the fidelity index goes only from -0.098 to 0.44 while the theoretical limits are -1 to 1 (Fried et al., 2019). In fact, the rows and the inter-rows are very close areas and can exchange species through dispersal process as wind, animals or agricultural engines. Moreover, the yearly alternation of tilled and covered inter-rows can bring the management of the inter-rows closer to the management of the rows (Angaud 2018). So, the difference between the rows and the inter-rows can be explained by the disturbance gradient between both areas but the proximity of the areas allowing plant dispersal avoids a complete separation of the two areas.

II. Differences of weed communities in the rows and in the inter-rows depending on the management practices and the environmental variables (weather, landscape and soil properties).

The fidelity index in the inter-rows (IR) showed a difference of weed communities' composition due to the various strategies adopted by the plants. First, our results showed a higher diversity (taxonomic: species richness and abundance; functional: functional richness and Rao's quadratic entropy) in the inter-rows than in the rows for the production mode, all the groups combining practices except the one with tillage management only and the linear model. These results emphasize that the higher diversity in the inter-rows comes from a difference of management between the areas. The weed communities managed by tillage in the rows and the inter-rows do not show a difference of diversity between both areas. That confirms the hypothesis 2, which assumed that the different managements in the rows and in the inter-rows through time and space create difference weed communities in both areas.

In fact, the pressure of management practices is lower in the inter-rows then in the inter-rows due to the proximity of the vines (competition) (Metay et al., 2018). The traits were also different between the rows and the inter-rows, with in the inter-rows hemicryptophytes, late flowering onset, anemogamous and animal dispersal; and in the rows favor therophytes, high SLA, long flowering duration, auto-apogamous, facultative entomogamous and Ellenberg's indicator for trophic level. This difference occurs between organic and conventional production mode, the group 3 representing mowing in the inter-rows and herbicides in the rows and in the linear model. The mowing in the inter-rows has less impact on diversity whereas herbicides or tillage management had an important impact on diversity and the same conclusion hold true for the traits. Same results were found in Saatkamp et al. (2014); Kazakou et al. (2016) and Fried et al. (2019), which consider mowing as low filter and tillage/herbicides as strong filter on weed communities. Former studies as Maillet (1992) showed opposite results with higher diversity under high intensity management but it was before the occurrence of systemic herbicides (glyphosate) which selected few species tolerant to them.

However, the first hypothesis is also partially confirmed due to the influence of external factors impacting the weed communities. The chemical products (insecticides and fungicides) containing copper can decrease the weed communities' diversity in the rows (Brun et al., 2003). The microclimate of the rows can be different to the inter-rows due to the shape of the vines on the rows (Shrestha and Fidelibus, 2005), the rain intensity (Dabney et al., 2001) and the size between the rows (Agreste, 2019). As Fried et al. (2019), our results revealed that it is possible to consider the rows and the inter-rows as different habitat or ecosystems (Millennium ecosystem, 2005) as "a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit" at the field level because of the different management practices applied on them, allowing different response traits and diversity (taxonomic and functional) at the vineyard scale.

III. Management practices and environmental variables acting as filters on biological type, dispersal and pollination modes and trophic level

The third question was to know if the management practices act as filters on weed communities and which are the main traits responding to different gradients. As seen in the previous paragraph, the difference of practices between the rows and the inter-rows provokes differences between weed communities. First, the management practices act as filters on diversity whether taxonomic and functional. In fact, the decrease of taxonomic diversity is often followed by a decrease of functional diversity, i.e. less species equal less different traits (Fried et al., 2016). The first part of the first hypothesis is confirmed. In fact, the organic manure and the number of mechanical passages which can be associated to organic production mode, enhance the diversity, whereas the weeding practices (tillage in IR, mowing in R, number of herbicide treatments), the proportion of sand and vineyard percentages at the landscape level (100m radius) decrease it.

The management practices as herbicides and tillage represent high disturbance and according to Saatkamp et al. (2014), high disturbed areas decrease the number of species because only the specialized ones can maintain their population. Sandy soil is considered as a poor soil and increases diversity in some studies (Fried and Maillet, 2018) but not here. The negative correlation between diversity and sandy soil can come from the correlation between tillage and sand percentage and the bigger influence of management practices than soil properties on diversity. The landscape also decreases the diversity with the homogeneity of landscape around the plot. The same result has been found in (Roschewitz et al., 2005) where homogeneous landscapes provide less species to fit with areas than heterogenous ones. In the IR, the tillage management has a lower diversity and, in the rows, it is the herbicides management. Moreover, the diversity is higher in the winter sampling period (March/April), which correspond to the period before the vineyards' works and high rate of rainfall and favorable conditions of soil moisture and temperature, so the spring period has the highest diversity (Baumgartner et al., 2008).

Secondly, RLQ – fourth corner, linear models, conventional versus organic production mode and groups analyses showed a positive correlation between the hemicryptophytes and the mowing management in the R and in the IR on one hand and a positive correlation between the tillage and the therophytes species. Those results are associated to the tillage management, which is absent when herbicide treatments are applied. Froud-Williams et al. (1983), Trichard et al. (2013) and Fried (2019) observe the same correlations. Moreover, as Lososovà et al. (2003), Kazakou et al. (2016) and MacLaren et al. (2019), the gradient of disturbance also shapes the weeds communities. The herbicides and tillage management can be considered as strong filters, selecting ruderal species (high SLA, low height and low seed lass) (Garnier et al., 2016), whereas the low disturbed management (mowing) acts as weak filter favoring hemicryptophytes, low SLA, high maximum height and high seed mass. The correlation between biological type and gradient of disturbance is also described in Porcova and Wikler (2014). Lososovà et al. (2003) study explained that by an effect of a transition from intensive agricultural management with repeated tillage and massive use of herbicides to soft management which takes care of environment with mowing and mulching. In vineyards with high level of herbicides treatment and high number of mechanical passages, weed communities contain more species with an early flowering onset and a long flowering duration. According to Gaba et al. (2014) and Garnier et al. (2016), these trait values allows a bypass by the species to the treatments, with a growing before the herbicides' application (Meiss et al., 2010).

The high disturbed areas also favor auto-apogamous, baro-autochory dispersal or facultative entomogamous, at the opposite, the low disturbed areas favor anemogamous, compulsory entomogamous and animal dispersal. The high disturbance involves other treatments as pesticides which can decrease the pollinators population and impact the weed communities and their reproduction (Fried et al., 2019). The negative correlation between chemical fertilization and compulsory entomogamous/animal dispersal confirms this hypothesis.

There is no impact of the fertilization on the trophic level (Ellenberg N) whether by the organic or the chemical one. This Ellenberg index can be interpreted as the growth of the plant thanks to the soil nitrogen availability (Moreau et al., 2013). At the opposite of what we expected, a positive correlation between Ellenberg_N and fertilization which represent species response to soil enrichment (Gaba et al., 2017), this correlation does not appear here.

Another combination has been highlighted by the RLQ – 4th corner analyses, with the positive correlation between the pH and the seed mass. The pH represents the rich soil with CaCO3 content and high pH. In Germany (Tautehahn et al., 2008) and in Fried et al. (2018) the same results have been found. The hypothesis proposed by Tautehahn et al. (2008) is that plant respond to competition for resources by bigger seeds to ensure the survival of population on alkaline soils. In fact, the competition on alkaline soil is high because the fertility is higher thus the density of vegetation is higher. Besides, Ellenberg (1996) showed that the calcareous species are mainly competitors and this hypothesis was confirmed after a comparison between the seed mass of ruderal and competitors (Tautehahn et al., 2008).

Some results in the study can be difficult to explain because of indirect effects. For example, the number of mechanical passages reflect the compaction of the soil, but also be synonym of the higher traffic in organic farming (Mezière et al., 2009), so, it can be understood that the number of mechanical passages has a positive impact on diversity.

Thirdly, the CWV of traits for the three approaches concerning the influence of management practices are lower under management practices (herbicides, tillage in the inter-rows, mowing in the rows), soil properties (sand percentage), vineyard percentage and under the rows. The scaled estimate of linear model showed also a lowest impact for the mowing that for the tillage of herbicide management. That means the high disturbed areas present a convergence of traits whereas the low disturbed areas present a divergence of traits. The same results have been found in Grime (2006) and Kazakou et al. (2016). That confirms that practices act on communities as filters reducing the range of possible trait values.

IV. What level of details in the description of farming practices is needed to explore the weeds' response?

The last question was about the best methodological point of view to adopt for analyzing the influence of management practices. Our results showed that the three approaches give more and more accurate information from production mode to raw variables of environment and management practices. So, the first hypothesis where the three approaches are complementary is partially confirmed, because different significant result appear in the three levels of method. However, combining all those results information is not easy. First, the even if the production mode results are significant, the causes of the results are confused. Bruggisser et al. (2010) and Nascimbene et al. (2012) showed that the impact of the production mode does not come from the management practices, so maybe it is the same here.

Moreover, it exists different degrees of organic management with either tillage or mowing as the dominant vegetation management practices and different intensity of conventional management depending on the types of chemical products and the quantity applied on the field (Gaba et al., 2014). Even MacLaren et al. (2019) took three level of production mode with organic, low input and high input, which are more representative. It is still interesting to see each step, one after another and to discover which a trait is linked to a practice, to a group and to a production mode. At the opposite, the raw variables are very accurate and explain each variable and their impact and allow comparing the level of disturbance between the practices. However, the linear models emphasize too many results and they are not always easy to describe and to interpret. The RLQ and fourth corner analyses are a good alternative to the linear model and return also combination which are significant and helpful to describe the practices impacts and the combinations of traits. We are never sure that the chosen practices are all relevant. The analysis by groups of similar management practices seem a good trade-off between both because the quantity of results is informative but not too detailed, it regroups the global strategy (IR/R) and it is more meaningful for the winegrowers.

V. Perspectives

The objectives of the thesis of Lorelei Cazeneuve (2017) were to know accurately the composition and the ecological characteristics of the viticultural flora, to determine the main filters allowing the present or not of the flora and to highlight the "sustainable" practices of the vineyards soil applied on the flora. The data of traits comes from BIOFLOR (Klotz et al., 2002), baseflor (Julve, 1998), LEDA (Kleyer et al., 2008), SID (Royal botanic garden, 2019) and Flora Gallica (Tison and Foucauld, 2014). The next step will be to measure the height, the seed mass, the SLA and other relevant traits on the field, instead to take the average trait values from traits databases. A strict protocol can be applied with a samples' collect describing in the handbook of Pérez-Harguindeguy et al. (2013), which indicate the number of replicated needed and describe the sampling protocol and the way to measure the traits.

Moreover, some the biological traits can be added to the study to obtain information about the practices into the soil. For that, the volume and size of roots can be relevant to understand the effects of the intensity and the depth of soil tillage (Gaba et al., 2017), or to understand how some plants escape to herbicides use. To end, the number of seeds can also inform on the tillage timing (Gaba et al., 2017) and being compared to the Grime's strategies (Grime, 1979). Another parameter which can be added to the study could have been the yield, which is an important element for the winegrower. However, two years are needed to get this data and the correlation between the weeds communities and the yield are not always clear because of some indirect effect. Kazakou et al. (2016) tried to demonstrate the difference of yield between mowing and tillage but the results were the same for both and a better characterization of the resources is preconized.

Conclusion

The weeds present in the Bordeaux vineyards respond to both management practices and the environment along a gradient of disturbance, competition and stress following Grime's strategies and combination of traits. The species in the inter-rows have a high maximum height at maturity, high seed mass, late flowering onset, short life cycle, low SLA and thus are often classified as competitor species. We emphasize that the practices (herbicides, mowing, tillage and fertilization) are important filter for selecting these strategies. The disturbance gradient exists and is important. The biological type is the first impacted trait, with therophytes in highly disturbed fields (herbicides, tillage) and hemicryptophytes in less disturbed fields (mowing). In highly disturbed fields, the traits converge with low height, high SLA, high flowering duration, early flowering onset and auto-apogamous pollination. In low disturbed fields, the traits diverge with short life cycle, low SLA, high maximum height, late flowering onset and anemogamous pollination. The environmental conditions are also responsible of traits selection such as sand percentage or the temperature, but always in combination with management practices. It is interesting to notice that there is a stronger relationship between combination of environmental variables and combination of traits, rather than between individual traits and individual environmental variable. When different practices are applied in the rows and in the inter-rows, the traits of the community differ, and as a consequence, the two areas (row/inter-rows) can be considered as two distinct habitats. The three approaches applied in this study put lights on different complementary results. However, the groups method (clustering fields according to their practices) and the RLQ – fourth corner analyses seem to be the easiest way to answer the wine growers' questions with relevant results.

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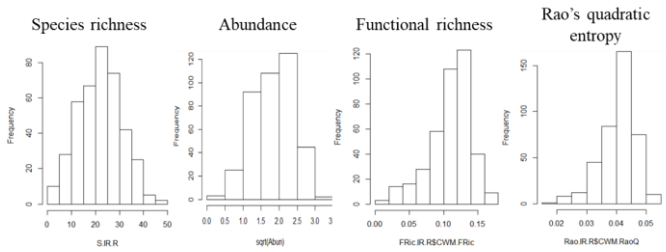
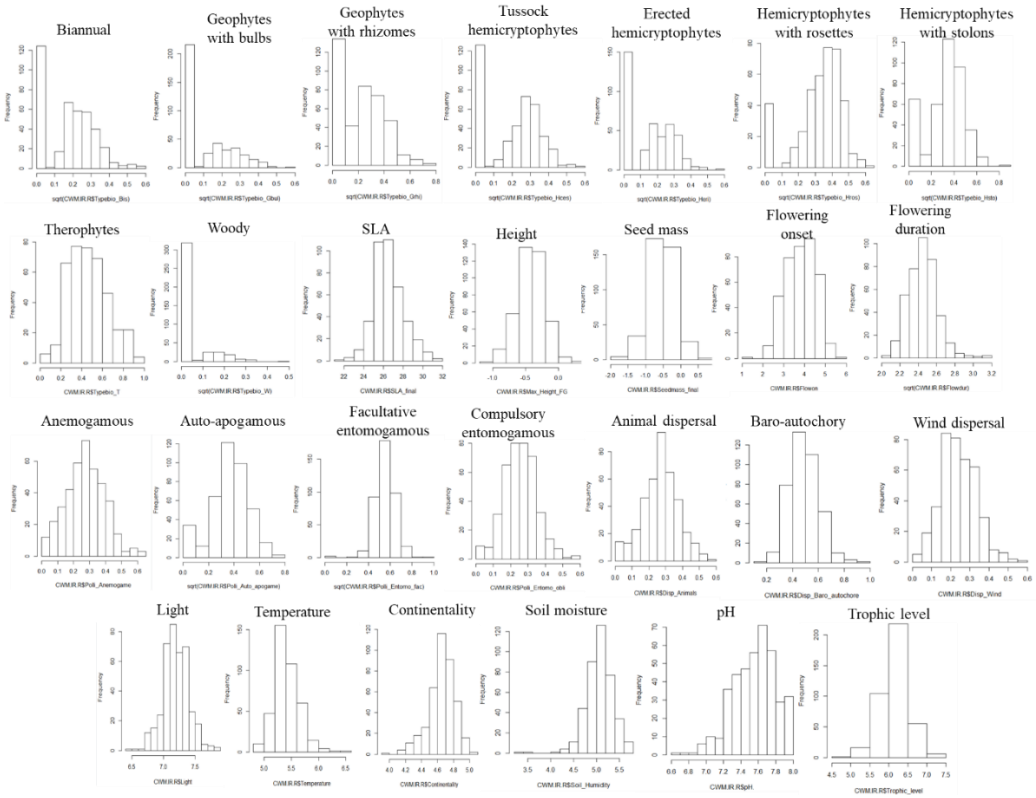
Appendices

Appendix I: Histograms of diversity's indices, CWM and CWV of traits

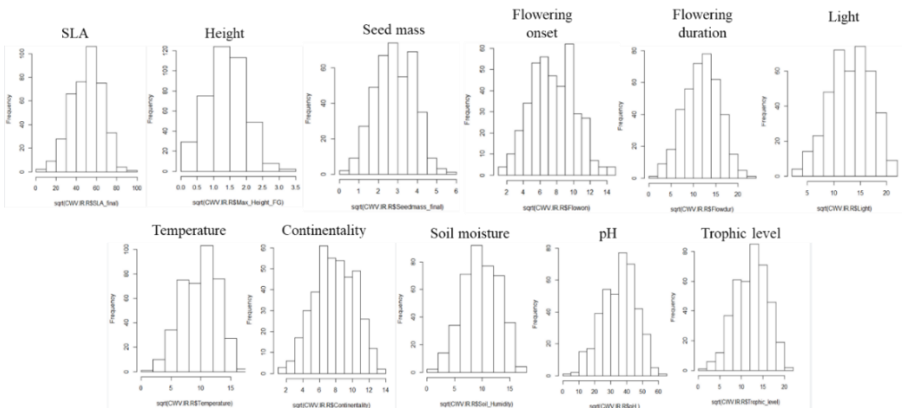
The diversity's indices



The CWM



The CWV



Appendix II: Inertia' tables explaining the traits' distribution to the axes of the Hill & Smith analysis applied on the matrix Q

Traits	Axis 1	Axis 2	Axis 3	Axis 4
Typeb.Bis	-6,428624	-5,14E-01	1,43328	-1,67183
Typeb.Gbul	-3,951951	-3,91E+00	30,30514	7,334904
Typeb.Grhi	-0,001707	-4,17E+00	-5,61363	2,7157
Typeb.Hces	0,150538	-3,18E+00	-14,62871	5,448521
Typeb.Heri	1,513544	-9,19E+00	3,98285	-12,248366
Typeb.Hros	-0,07797	1,56E-02	-0,96782	-9,900744
Typeb.Hsto	0,066974	-2,29E+00	-10,31879	8,175466
Typeb.T	3,611113	3,22E+01	0,49686	-0,002362
Typeb.W	-4,933596	-2,42E-01	0,38333	-1,84566
SLA	26,598607	1,11E+01	-3,66207	3,156524
Height	-0,00107	-4,04E+01	0,19316	-8,455616
Seedmass	-1,736187	-7,00E+00	41,88158	6,973451
Flowon	-10,177398	-4,03E+01	-7,57946	-6,452259
Flowdur	39,235387	1,70E+01	-0,00174	0,022838
Polli.Anemogame	-2,212369	-1,23E+01	-35,55276	8,380413
Polli.Auto_apogame	3,977539	6,31E+00	-1,24429	-8,059934
Polli.Entomo_fac	2,471316	1,69E+00	10,33078	-12,820205
Polli.Entomo_obli	-2,735613	2,60E-04	7,1415	9,231441
Disp.Animals	-1,740631	-1,40E+00	-0,94077	28,055455
Disp.Baro_autochore	0,842847	-2,47E-02	3,877	0,032846
Disp.Wind	0,183039	2,16E+00	-1,24875	-35,961677
Light	-21,794172	1,79E+00	-7,86602	-14,871291
Temperature	-37,05016	6,89E+00	0,62367	6,429956
Continentality	39,68911	-1,62E+01	0,25159	-2,184837
Soil_Humidity	15,491834	-1,02E+01	-12,74919	6,003863
pH	7,80207	-1,49E+01	7,21707	-0,3214
Trophic_level	34,620608	-6,44E+00	3,78018	1,141252

Appendix III: Groups results after performing a PCA and a HCA on the practices (101 plots)

For the first part of this analysis, we worked at the level of the 101 fields (instead of the 400 floristic samples). Based on the Hierarchical Cluster Analysis and the Mantel statistic, we found four groups to best describe the practices. The three first axes of the PCA explained 67.77% of the total variability of the practices' matrix (Figure 11).

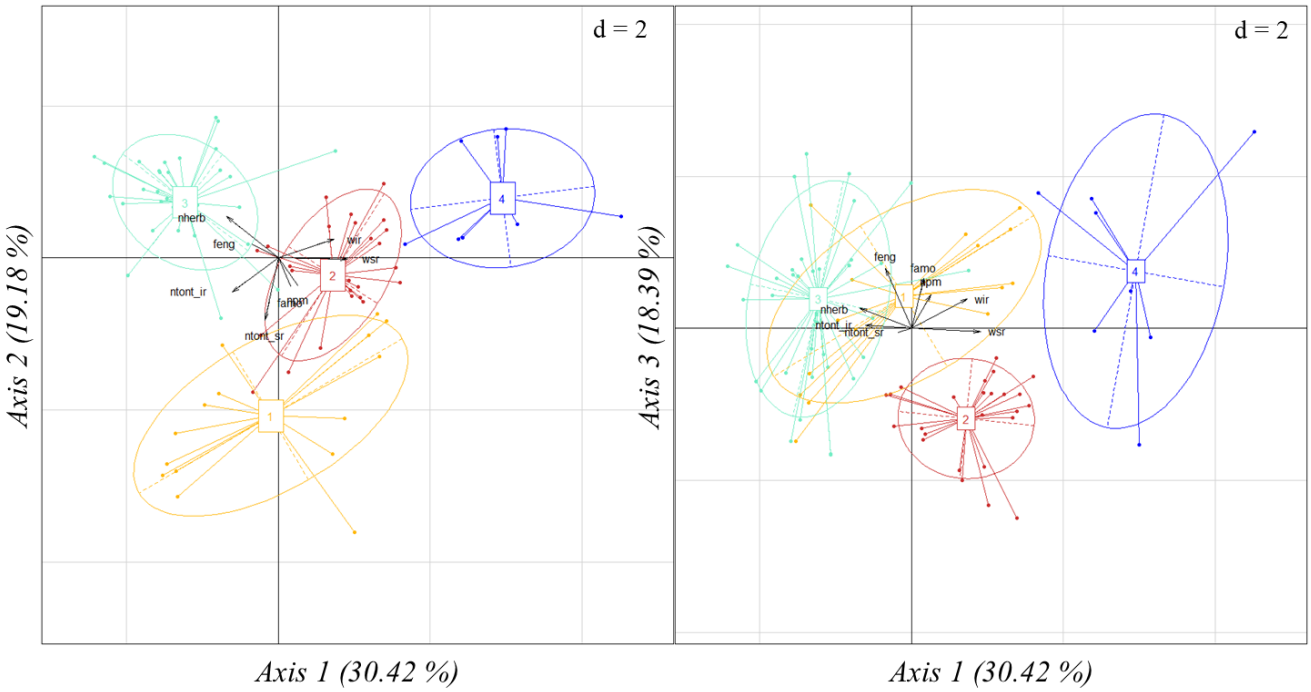


Figure 11: Graphs of the 4 groups displayed after a PCA applied on the 101 plots in function of the practices (black arrows)

The 1st group (in yellow) contained 17 fields including 10 organic plots and 7 conventional plots. It was positively correlated with the number of mowings in the rows (v_test = 6.92, p_value = 4.54e-12) and in the inter-rows (v_test = 3.18, p_value = 1.48e-04), and also with organic fertilization (v_test = 3.68, p_value = 2.37e-04) and the number of mechanical passages (v_test = 2.75, p_value = 5.67e-03). The group 1 was negatively correlated to the number of herbicides treatments (v_test = -3.54, p-value = 4.07e-04) (Figure 6). Table 15 shows the mean values of management practices per group and confirmed the highest mean of the group 1 the mowing in the rows (2.76) and in the inter-rows (4.76), the organic fertilization (8.41) and the number of mechanical passages (30).

The 2nd group (in red) contained 28 fields, 14 organic and 14 conventional fields. The group 2 was positively correlated with the number of tillage in the rows (v_test = 3.97, p_value = 7.28e-05) and negatively with the number of tillage in the inter-rows (v_test = -2.26, p_value = 2.34e-02), with both organic (v_test = -2.66, p_value = 7.91e-03) and chemical fertilization (v_test = -5.74, p_value = 9.61e-09) and with the number of herbicides treatments (v_test = -4.37, p_value = 1.24e-05) (Figure 6). Table 15 also indicated that this group had the highest mean for the organic fertilization and a high mean for the mowing in the inter-rows.

The 3rd group (in green) contained 44 fields with 6 organic fields and 38 conventional fields, it's the biggest group. This group was positively correlated with the number of herbicides treatments(v_test = 8.63, p_value = 6.07e-18), the number of chemical fertilization (v-test = 4.57, p_value = 4.79e-06) and the number of mowings in the inter-rows (v_test = 2.66, p_value = 7.75e-03). The group 3 was negatively correlated with the number of mechanical passages (v_test = -2.14, p_value = 3.20e-02), the number of tillage in the rows (v_test = -6.72, p_value = 1.82e-11) and in the inter-rows (v-test = -2.20,

p_value = 2.78e-02) and the number of mowings in the rows (v-test = -3.65, p_value = 2.62e-04) (Figure 6). Table 15 confirmed the high means of group 3 for the number of herbicides treatments, the number of mowings in the inter-rows and the number of chemical fertilizations.

The 4th group (in blue) contained 12 fields with 8 organic fields and 4 conventional fields. This group was positively correlated with tillage in both the inter-rows (v_test = 7.62, p_value = 2.56e-14) and the rows (v-test = 5.40, p_value = 6.66e-08). The group 4 was negatively correlated with the number of herbicides treatments (v_test = -3.09, p_value = 1.99e-03) and mowing in the inter-rows (v_test = -6.19e-10) (Figure 6). Table 15 confirmed the high means of group 4 for the number of tillage in the rows and in the inter-rows and additionally highlighted the high number of mechanical passages.

Table 15: Means of each practice per group (numbers in bold are significant) The practices' names are described in the material and method part I.3 Agricultural practices

moy	**Feng**	**Famo**	**Nherb**	**Wir**	**Wsr**	**Ntont_ir**	**Ntont_sr**	**Npm**
1	2.24	**8.41**	0.06	0.33	1.94	**4.76**	**2.76**	**30**
2	0.21	**5.43**	0.14	1.16	**3.71**	**3.18**	0.5	25.86
3	**3.20**	6.23	**1.91**	1.05	0.41	**4.05**	0.05	25.39
4	2.50	6.92	0	**5.67**	**5.67**	0.50	0	**28.83**

Appendix IV: PCA performing to choose environmental variables including the climatic conditions, landscape, the soil properties and the management practices for linear models

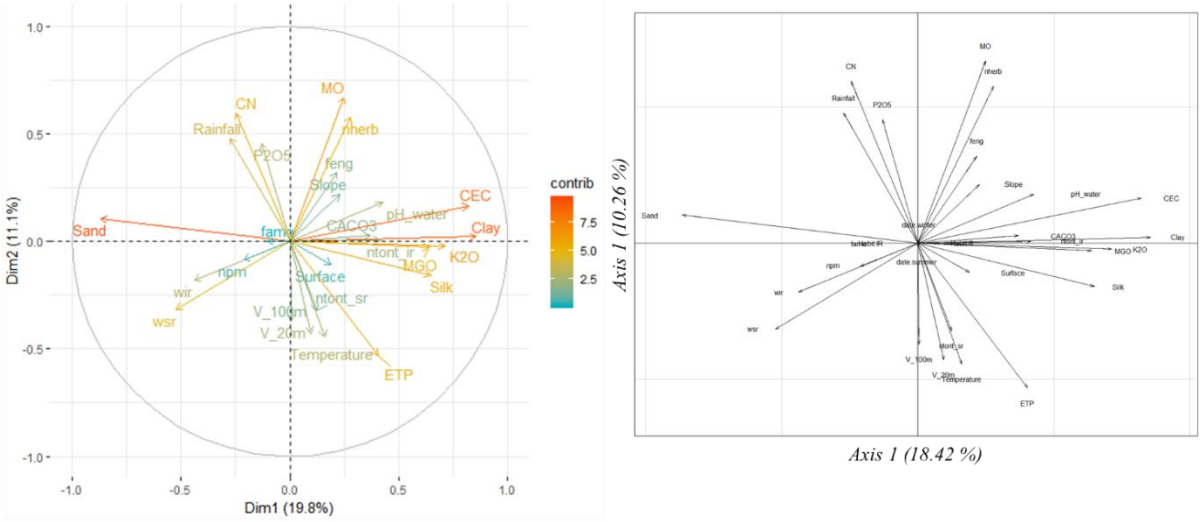


Figure 12: Correlation circle of environmental variables with their contribution on the left and with the habitat and the sampling period on the right

The correlation circle on the left gave the contribution of each variable for the axes. It represented 30.9 % of the total inertia. On the right, a Hill & Smith was performed to see the impact of the sampling period (winter/summer) and of the habitat (rows/inter-rows), which are qualitative variables. The habitat was correlated with the first axis, positively for the rows and negatively for the inter-rows. The sampling period was correlated with the second axis, positively with the winter period and negatively with the summer period. Besides, the clay and the silk percentages were negatively correlated with the sand percentage. The water pH was positively correlated with the cation exchange capacity (CEC), the CaCO3, the MgO and the K2O. The pH indicated a rich soil in this study. The rainfall was negatively correlated with the evapotranspiration (ETP) and the temperature. The C/N ratio was positively correlated with the P2O5. The vineyard percentage at 100 m radius was positively correlated with the surface and the vineyard percentage at 20 m radius. The slope was positively correlated with the number of herbicides, and the organic matter content.

So, the variables kept, for the linear models with interaction, were: the vineyard percentage at 100 m radius (V_100 m), the sand percentage (Sand), the organic matter (MO), the C/N ratio (CN), the pH (pH), the rainfall and the eight the management practices: mowing in the rows (ntont_sr), mowing in the inter-rows (ntont_ir), tillage in the rows (wsr), tillage in the inter-rows (wir), organic manure (famo), chemical fertilization (feng) and number of mechanical passages (npm).

Appendix V: Production modes' influence (organic/conventional) on CWM and CWV of traits

The CWM of hemicryptophytes (tussock, rosettes, stolons), flowering onset, anemogamous and animal dispersal were higher in the inter-rows than in the rows (Table 16, Figure 13). At the opposite, the CWM of therophytes, SLA, flowering duration, auto-apogamous, facultative entomogamous, wind dispersal, Ellenberg's indicator for trophic level were higher in the rows than in the inter-rows. The CWM of hemicryptophytes (tussock, stolons) and anemogamous higher for organic production mode. The CWM of therophytes, facultative entomogamous, wind dispersal and Ellenberg's indicator for trophic level were higher in the conventional production mode. There were some significant interactions between the area and the production mode for the CWM of hemicryptophytes (tussock, stolons), therophytes, anemogamous, auto-apogamous and wind dispersal. The CWV of all traits were higher in the inter-rows than in the rows and higher in the organic than in the conventional production mode (except maximum of height which was not significant for the production mode) (Table 17, Figure 14). The were some significant interaction between areas and production mode for the CWV of flowering onset.

Table 16: The F_value, the estimate and the significance concerning the habitat, the production mode and the interaction between both for the CWM. The point (.) indicates a p_value above 0.05, the stars indicates a p_value between 0.05 and 0.01 with one star (*), a p_value between 0.01 and 0.001 with two stars (**) and a p_value under 0.001 with three stars (***). The adjusted square-root (R^2) indicates the contribution of area, production mode and their interaction of each trait.

Higher score in IR | Higher score in R | Higher score in conventional production mode | Higher score in organic production mode

Traits	R^2 (adjusted)	Area	Production mode	Interaction
Tussock hemicryptophytes	0.15	**52.6/-0.1 *****	**11.7/-0.1 *****	3.6/0.1 .
Hemicryptophytes with rosettes	0.15	**59.2/-0.1 *****	0.1/-0.01	**6.9/0.1 ***
Hemicryptophytes with stolons	0.07	**29.7/-0.1 *****	**6.6/-0.06 ***	**5.9/0.1 ***
Therophytes	0.11	**44.2/0.2 *****	**11.2/0.1 ****	**6.2/-0.1 ***
SLA	0.03	**13.6/0.7 *****	0.4/0.1	0.6/-0.3
Height	0.02	0.9/-0.02	2.6/0.1	1.04/0.04
Seed mass	<0.001	0.1/-0.02	0.8/0.1	<0.001/-0.001
Flowering onset	0.02	**10.0/-0.3 ****	0.1/-0.04	1.5/0.2
Flowering duration	0.08	**25.6/0.1 *****	0.5/-0.02	2.6/-0.05
Anemogamous	0.13	**58.4/-0.1 *****	**5.1/-0.04 ***	**12.4/0.1 *****
Auto-apogamous	0.02	**7.5/0.1 ***	0.04/<0.001	2.9/-0.1
Facultative entomogamous	0.03	**7.9/0.03 ***	**6.2/0.03 ***	1.0/-0.02
Compulsory entomogamous	-0.01	0.2/0.01	0.5/0.01	0.7/-0.02
Animal dispersal	0.03	**13.1/-0.1 *****	1.5/-0.02	1.9/0.03
Baro-autochory	0.01	2.6/0.02	0.4/-0.01	0.3/0.01
Wind dispersal	0.1	**4.9/0.03 ***	**4.9/0.03 ***	**5.0/-0.04 ***
Trophic level	0.04	**16.2/0.2 *****	**3.9/0.1 ***	1.5/-0.1

Table 17: The F_value, the estimate and the significance concerning the habitat, the production mode and the interaction between both for the CWV values. The points (.) indicated a p_value above 0.05, the stars indicated a p_value between 0.05 and 0.01 with a star (*), a p_value between 0.01 and 0.001 with two stars (**) and a p_value under 0.001 with three stars (***). The adjusted square-root (R^2) indicates the contribution of area, production mode and their interaction of each trait.

Higher score in IR | Higher score in R | Higher score in conventional production mode | Higher score in organic production mode

Traits	R^2 (adjusted)	Area	Production mode	Interaction
SLA	0.32	**105.8/-16.5 *****	**14.0/6.9 *****	3.3/4.7 .
Height	0.14	**49.4/-0.5 *****	0.7/0.1	2.9/0.2 .
Seed mass	0.33	**111.5/-1.1 *****	**14.7/0.5 *****	1.7/0.2
Flowering onset	0.37	**144.9/-3.2 *****	**11.1/1.0 ****	**5.1/1.0 ***
Flowering duration	0.19	**52.7/-3.2 *****	**7.2/1.4 ****	1.7/1.0
Trophic level	0.31	**99.4/-3.9 *****	**16.3/1.8 *****	2 .4/1.0

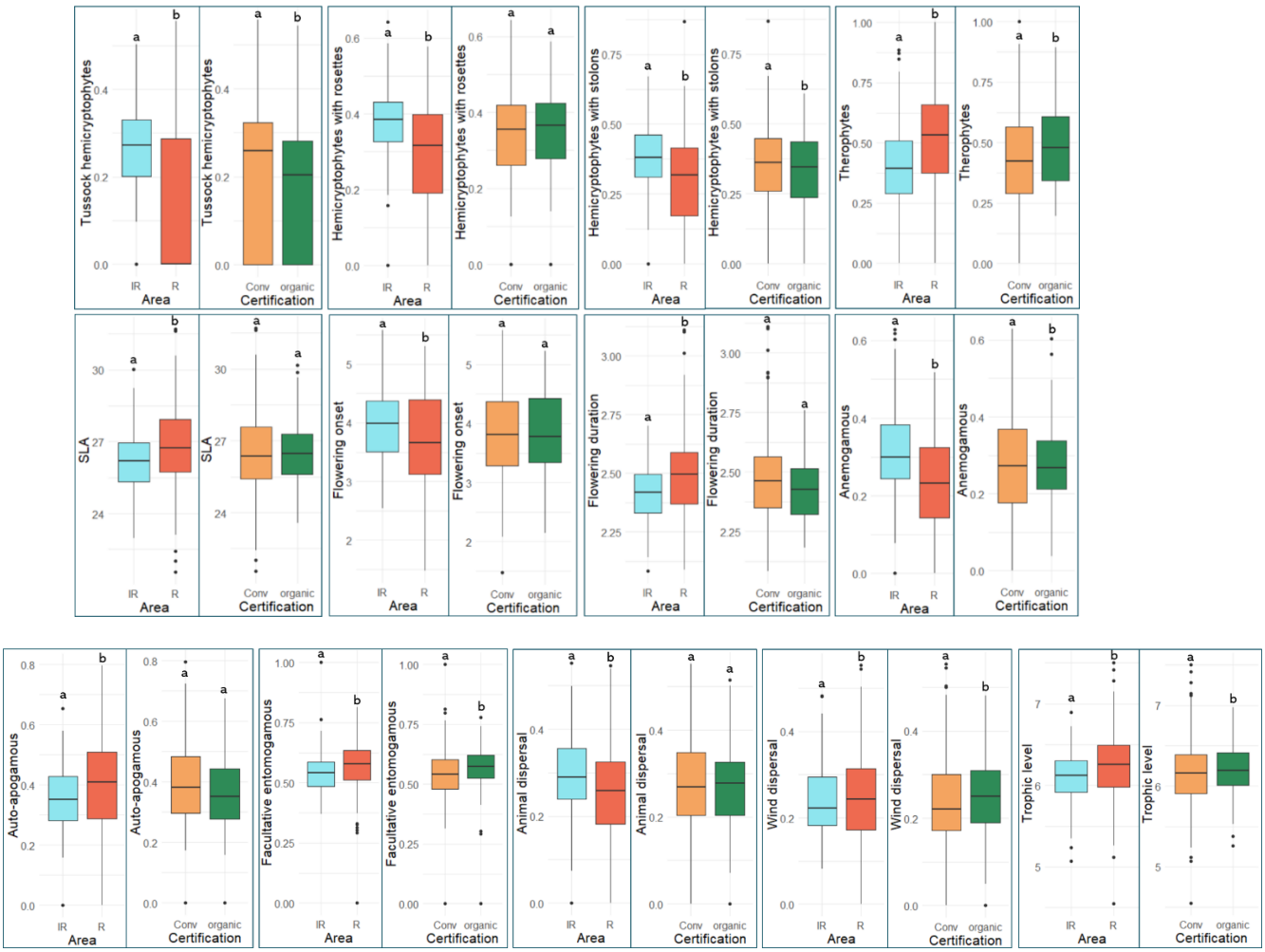


Figure 13: Boxplots of CWM of traits with the areas in blue for the inter-rows, in red for the rows, in yellow for conventional and in green for organic production mode.

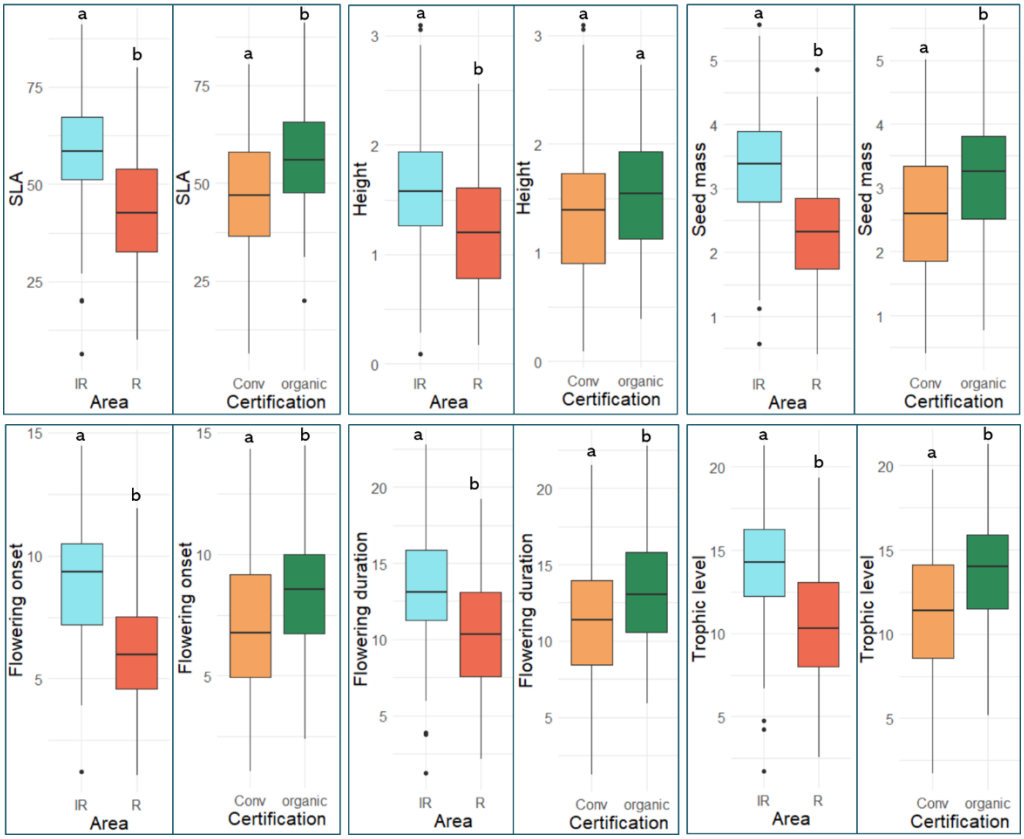


Figure 14: Boxplots of CWV of traits with the areas in blue for the inter-rows, in red for the rows, in yellow for conventional and in green for organic production mode.

Appendix VI: Influence of groups of practices on the CWM and CWV of traits

The CWM of hemicryptophytes (tussock and rosettes) and anemogamous were higher in the inter-rows than in the rows (Table 18). The CWM of hemicryptophytes with stolons, flowering onset, facultative entomogamous and animal dispersal were higher in the inter-rows than in the rows for the group 3 whereas the CWM of therophytes, SLA, flowering duration and Ellenberg's indicator for trophic level were higher in the rows than in the inter-rows for the group 3 (Appendix VII). The CWM of tussock hemicryptophytes was higher in the inter-rows than in the rows for the four groups. The CWM of hemicryptophytes were higher in the inter-rows than in the rows for the group 1 and 3. The CWM of anemogamous were higher in the inter-rows than in the rows for the groups 2 and 3.

For the inter-rows, the CWM of hemicryptophytes (tussock, rosettes, stolons) and animal dispersal were higher in the groups 1,2 and 3 than in the group 4, whereas the CWM of therophytes and facultative entomogamous were higher in the group 4 than in the other groups. The CWM of seed mass was higher in the groups 2 and 3 more than in the group 4. The CWM of compulsory entomogamous was higher in the group 2 than in the group 4. The CWM of wind dispersal was higher in the group 1 than in the group 3 and was higher in the group 4 than in the groups 2 and 3.

For the rows, the CWM of hemicryptophytes with stolons was higher in the groups 1 and 2 than in the groups 3 and 4, whereas the CWM of therophytes was higher in the groups 3 and 4 than in the groups 1 and 2. The CWM of maximum height was higher in the group 2 than in the group 3, whereas the CWM of baro-autochory was higher in the group 3 than in the group 2. The CWM of flowering duration was higher in the group 3 than in the other groups. The CWM of tussock hemicryptophytes was higher in the groups 2 and 3 than in the group 4. The CWM of compulsory entomogamous was higher in the group 2 than in the groups 3 and 4.

The CWV of all traits were higher in the inter-rows than in the rows for the groups 1, 2 and 3, except for the CWV of seed mass, which was higher in the inter-rows in the four groups (Table 19). In the inter-rows, the CWV of SLA, flowering onset, flowering duration and Ellenberg's indicator for trophic level were higher in the groups 1, 2 and 3 than in the group 4. In the rows, the CWV of SLA, seed mass, flowering onset, Ellenberg's indicator for trophic level were higher in the groups 1 and 2 than in the group 3.

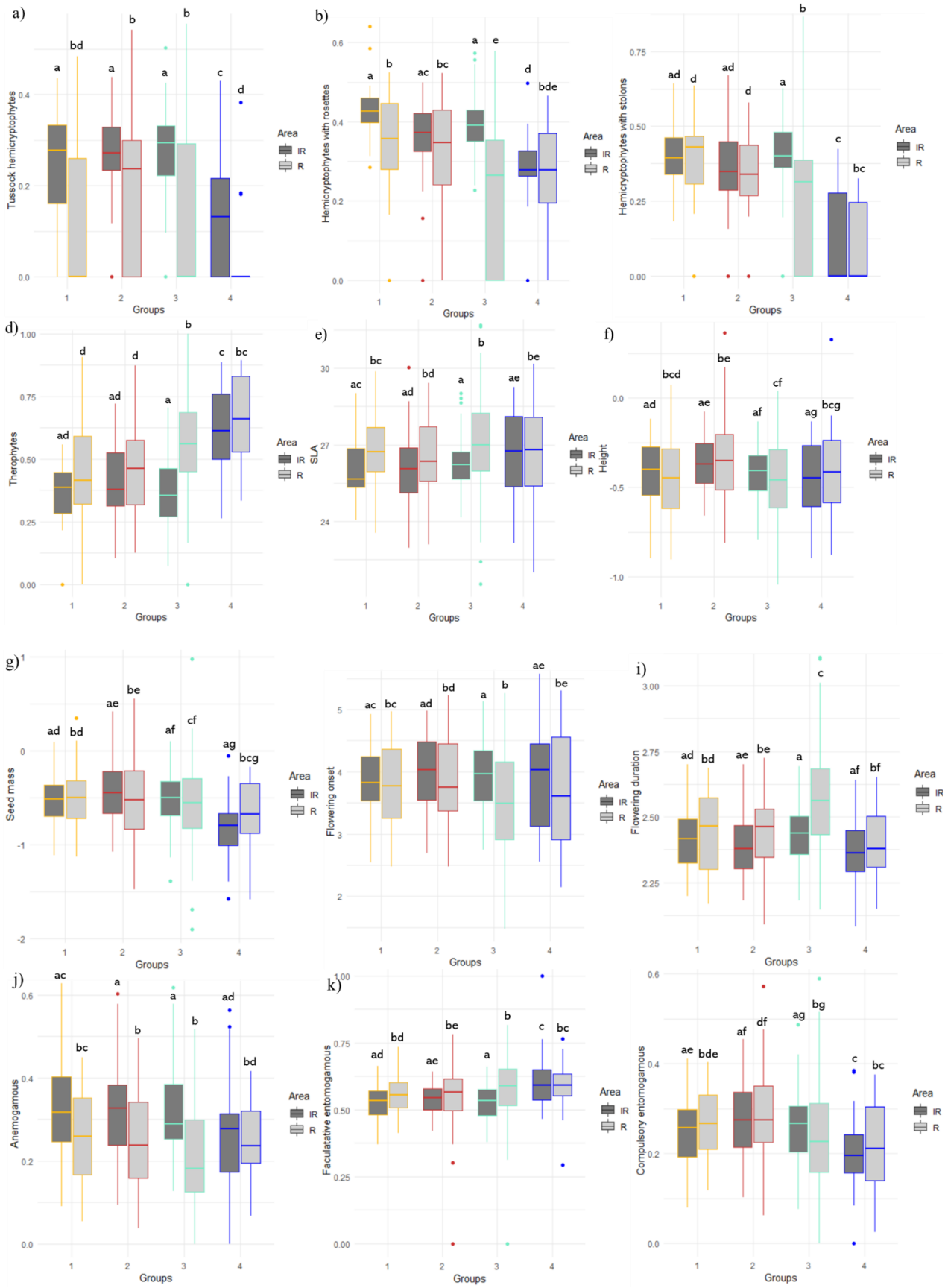
Table 18: Linear model with interaction's results of the diversity's indices. The points (.) indicated a p_value above 0.05, The stars indicated a p_value between 0.05 and 0.01 with a star (*), a p_value between 0.01 and 0.001 with two stars (**) and a p_value under 0.001 with three stars (***).

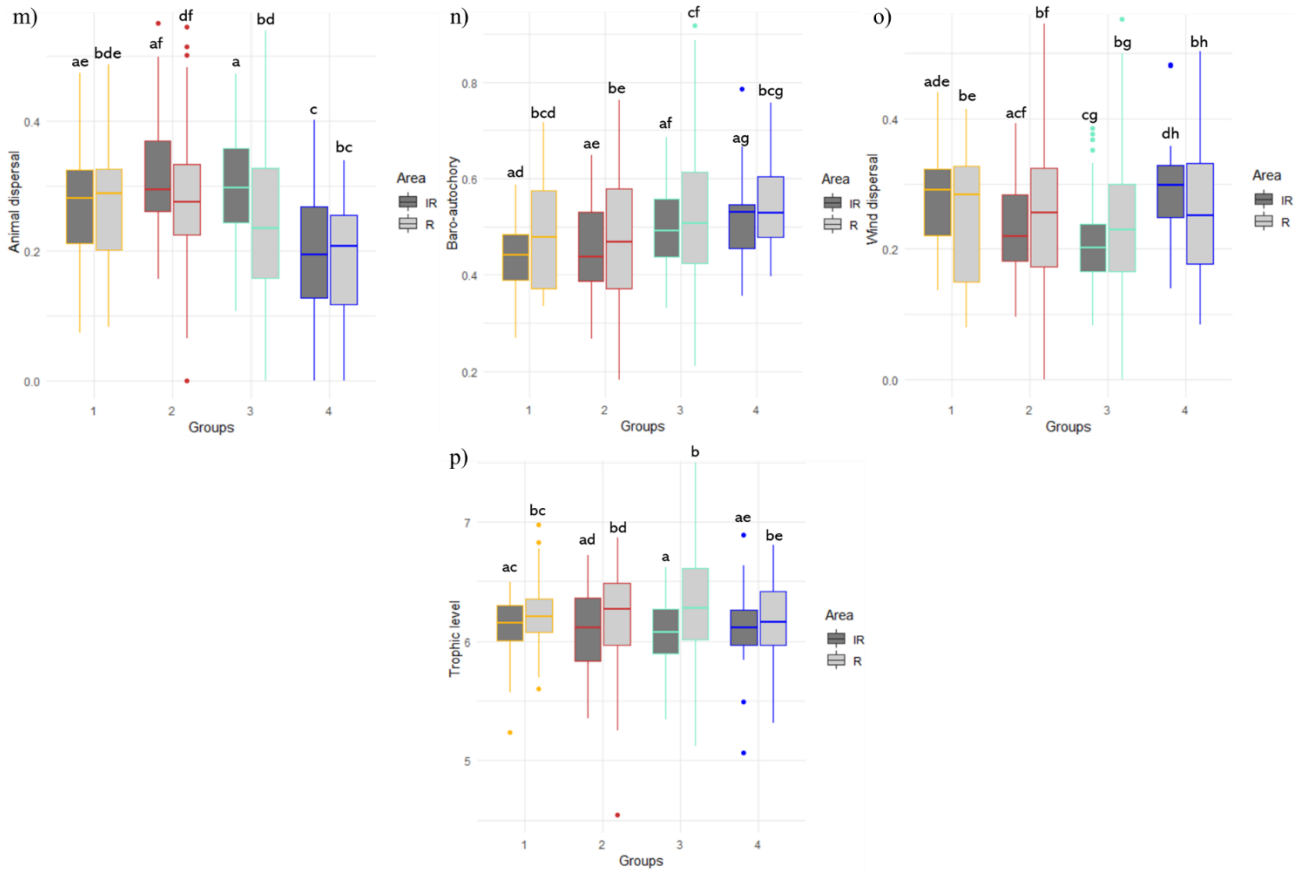
CWM Traits	Area (rows/inter-rows)	Groups	Interaction
Tussock hemicryptophytes	11.6 ***	**7.7 *** **	0.5
Hemicryptophytes with rosettes	9.4 **	**7.7 *** **	**7.0 *** **
Hemicryptophytes with stolons	0.4	**22.1 *** **	**5.3 ** **
Therophytes	3.5	**13.1 *** **	**5.2 ** **
SLA	3.6 .	0.7	0.9
Height	0.03	1.0	0.8
Seed mass	0.1	**5.7 *** **	1.3
Flowering onset	0.3	0.1	1.1
Flowering duration	1.4	1.8	**3.0 * **
Anemogamous	4.1 *	1.4	2.1 .
Auto-apogamous	0.2	1.0	0.9
Facultative entomogamous	2.0	**4.4 ** **	1.6
Compulsory entomogamous	0.6	**3.4 * **	1.2
Animal dispersal	0.4	**7.7 *** **	1.2
Baro-autochory	2.7	**3.5 * **	0.3
Wind dispersal	1.6	**8.6 *** **	2.1
Trophic level	1.4	0.1	1.6

Table 19: Linear model with interaction's results of the diversity's indices. The points (.) indicated a p_value above 0.05, the stars indicated a p_value between 0.05 and 0.01 with a star (*), a p_value between 0.01 and 0.001 with two stars (**) and a p_value under 0.001 with three stars (***).

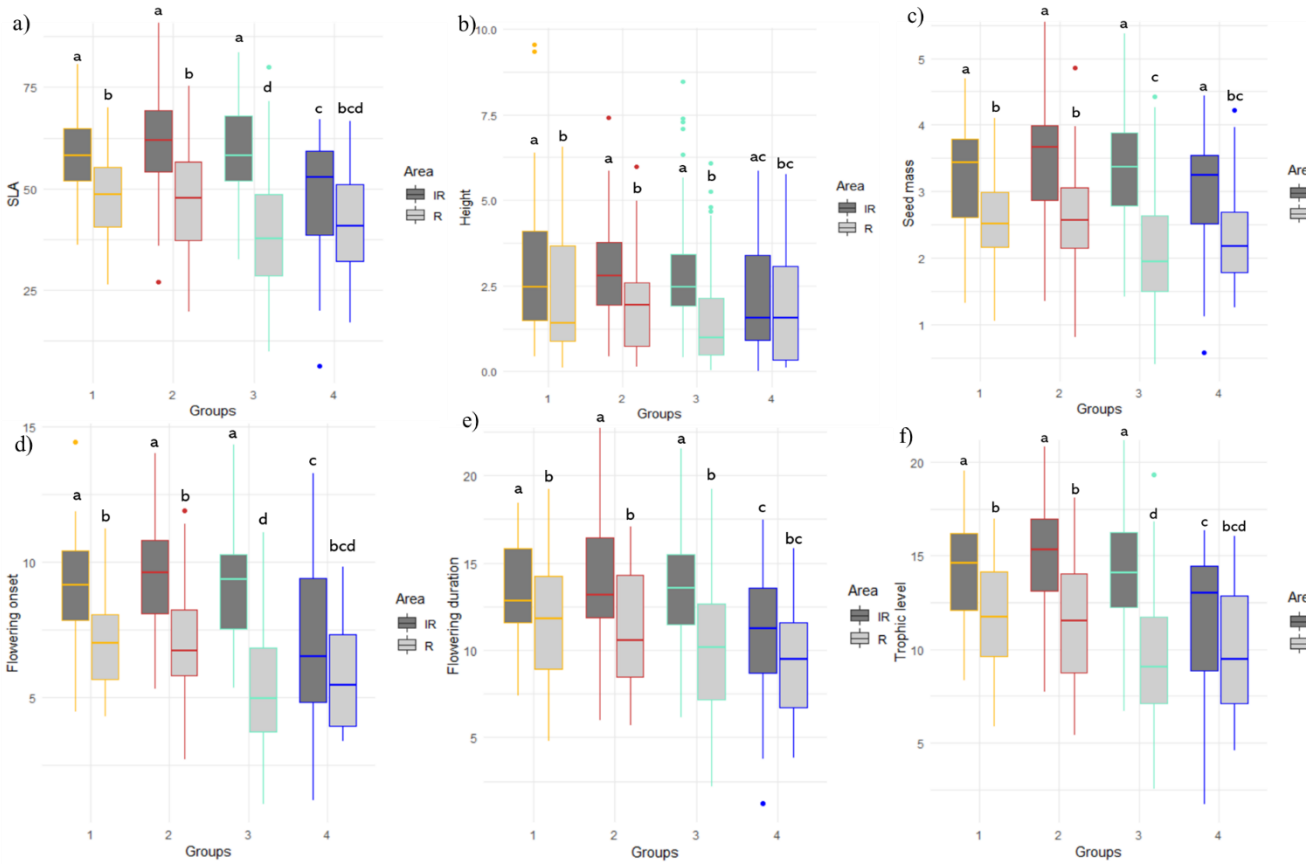
CWV traits	Area (rows/inter-rows)	Groups	Interaction
SLA	9.8 **	6.2 ***	4.8 **
Height	5.4 *	2.2 .	2.3 .
Seed mass	12.3 ***	2.4 .	3.5 *
Flowering onset	15.4 ***	8.3 ***	6.9 ***
Flowering duration	5.0 *	5.6 ***	2.1
Trophic level	10.4 **	6.6 ***	3.7 *

Boxplots of the CWM of traits





Boxplots of the CWV of traits

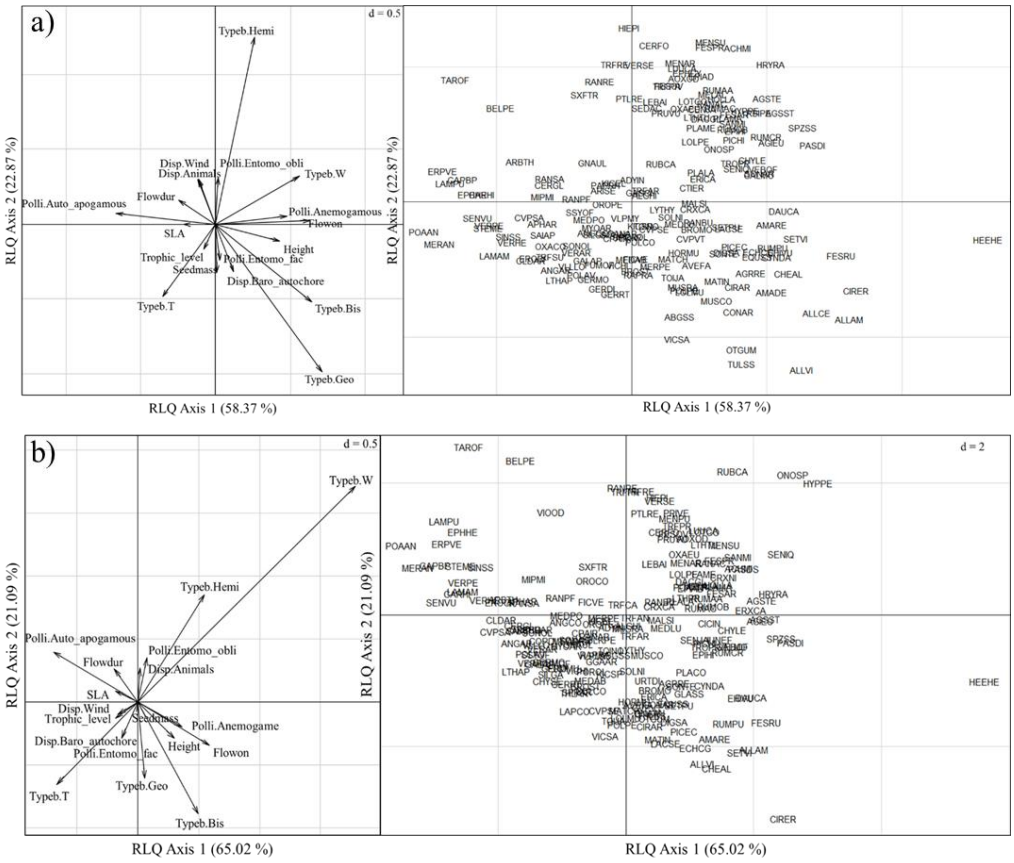


Appendix VII: RLQ analyses of the rows (a) and the inter-rows (b)

The first two axes of the RLQ for the rows (a) accounted for 81.24% of the total inertia (58.37 % and 22.87% for the RLQ axis 1 and 2, respectively). The first axes of the RLQ for the inter-rows (b) accounted for 86.11 % of the total inertia (65.02 % and 21.09 % for the RLQ axis 1 and 2, respectively).

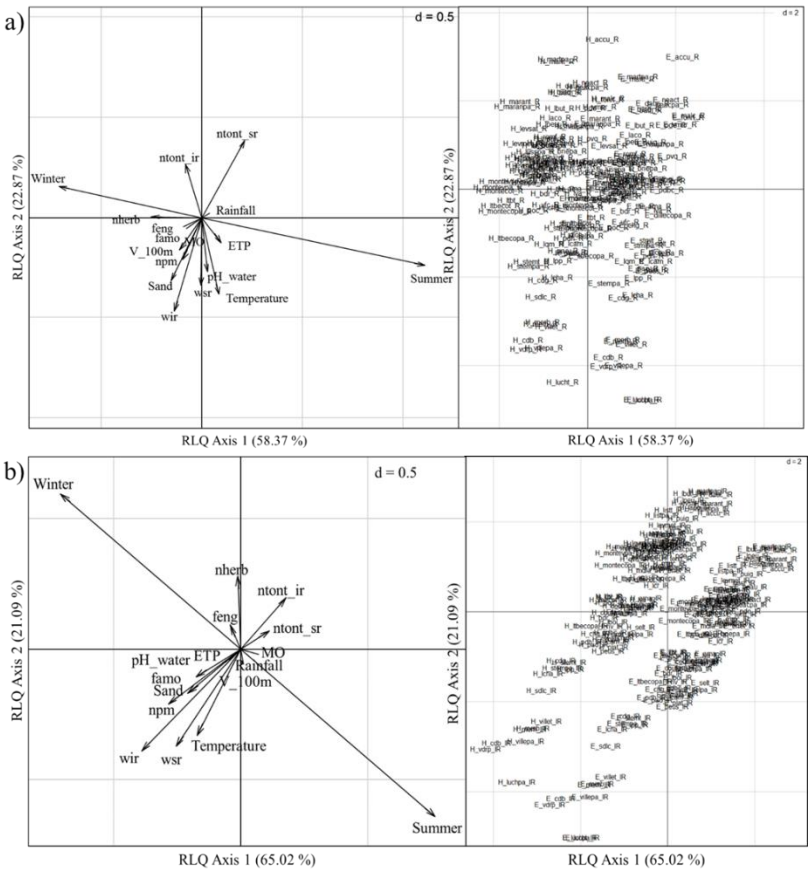
First of all, for the rows, the first axis was positively correlated with the flowering onset, the anemogamous, the height, the woody and biannual plants. At the opposite, the first axis was negatively correlated with the flowering duration, the auto-apogamous and the SLA. The second axis was positively correlated with the hemicryptophytes, the wind dispersal, the animal dispersal and the compulsory entomogamous. At the opposite, the second axis was negatively correlated with the therophytes, the trophic level, the seed mass, the facultative entomogamous and the baro-autochory.

Secondly, for the inter-rows, the first axis was positively correlated with the flowering onset, the height, the anemogamous and the woody plant. At the opposite, the second axis was negatively correlated with the SLA, the flowering duration, the auto-apogamous, the wind dispersal and the trophic level. The second axis was positively correlated with the hemicryptophytes, the compulsory entomogamous and the animal dispersal. At the opposite, the second axis was negatively correlated with the therophytes, the baro-autochory, the facultative entomogamous, the geophytes, the biannual and the seed mass.



For the environmental variables including the management practices, the rows (a) and the inter-rows (b) had a positive correlation between the first axis and the summer sampling period and a negative correlation between the first axis and the winter sampling period. For the rows, the mowing practices in the rows and in the inter-rows were opposed to the tillage in the rows and in the inter-rows, to the sand percentage, the number of mechanical passages, the temperature, the organic matter and the pH. The number of herbicides, the chemical fertilization and the organic manure were opposed to the rainfall and the evapotranspiration. The opposition seemed to be the same for the inter-rows. In both case, the

mowing was opposed to the tillage management practices and the herbicides and the chemical fertilization were orthogonal to this opposition as a third direction.



Appendix VIII: Linear model for CWM and CWV of traits

The CWM of tussock hemicryptophytes, therophytes, SLA, flowering duration, auto-apogamous, anima dispersal, wind dispersal and Ellenberg's indicator for trophic level were higher during the winter period, whereas the CWM of hemicryptophytes with stolons, maximum height, flowering onset, anemogamous and baro-autochory were higher during the summer period. The CWM of hemicryptophytes (tussock, rosettes, stolons), flowering onset, anemogamous and animal dispersal were higher in the IR, whereas the CWM of therophytes, SLA, flowering duration, auto-apogamous, facultative entomogamous, baro-autochory and Ellenberg's indicator for trophic level were higher in the R (Table 13).

The sand percentage and the organic matter were positively correlated with the CWM of therophytes, facultative entomogamous and Ellenberg's indicator for trophic level and negatively with hemicryptophytes, flowering onset, auto-apogamous and wind dispersal. The pH was positively correlated with the CWM of maximum height, seed mass, facultative entomogamous, baro-autochory and Ellenberg's indicator for trophic level and negatively with the CWM of hemicryptophytes, auto-apogamous and wind dispersal. The C/N ratio was positively correlated with hemicryptophytes (all) and negatively with therophytes, height and Ellenberg's indicator for trophic level (Table 13).

The organic manure was positively correlated with CWM of hemicryptophytes, therophytes, seed mass, auto-apogamous and animal dispersal and negatively with CWM of flowering onset. The chemical fertilization was negatively correlated with CWM of compulsory entomogamous and animal dispersal. The number of herbicide treatments was positively correlated with CWM of tussock hemicryptophytes, flowering duration, auto-apogamous and Ellenberg's indicator for trophic level and negatively with CWM of height, flowering onset and anemogamous. Soil tillage in the inter-rows was positively correlated with CWM of therophytes, SLA, auto-apogamous, facultative entomogamous and baro-autochory and negatively with CWM of hemicryptophytes, maximum height, anemogamous, compulsory entomogamous and animal dispersal. Mowing in the rows was positively correlated with CWM of hemicryptophytes and anemogamous and negatively with CWM of therophytes, flowering duration and baro-autochory. There was no correlation between the mowing in the inter-rows and the traits. The number of mechanical passages was positively correlated with CWM of therophytes, flowering duration, auto-apogamous and Ellenberg's indicator for trophic level and negatively with CWM of hemicryptophytes, flowering onset, anemogamous and compulsory entomogamous (Table 13).

The rainfall was positively correlated with CWM of maximum height and wind dispersal and negatively with baro-autochory.

The CWV of all traits showed similar results with higher CWV during winter period (except for the CWV of flowering onset which was higher during the summer period) and higher CWV in the IR than in the R. The CWV of the traits were positively correlated with organic matter content (except for seed

mass), organic manure (except for seed mass and flowering onset) and number of mechanical passages (except for flowering duration).

Moreover, the CWV of seed mass was positively correlated with C/N ratio and mowing in the IR. The CWV of traits were negatively correlated with vineyard and sand percentages (except for the CWV of SLA and maximum height), number of herbicide treatments, tillage in the IR (except for the CWV of maximum height and seed mass) and mowing in the R (except for the CWV of seed mass) (Table 14).

Table 13: Linear models given the F_value and the estimate for the CWM traits values. A compartment in color is significant, green for the positive interactions and yellow for the negative ones. The point (.) indicate a p_value above 0.05, the stars indicated a p_value between 0.05 and 0.01 with one star (*), a p_value between 0.01 and 0.001 with two stars (**) and a p_value under 0.001 with three stars (***).

Traits/Var	Date Winter	Area R	V_100 m	Sand	MO	CN	pH	feng	famo	nherb	wir	wsr	Nton t_ir	Ntont_ sr	npm	Rainfall
Hemi tussock	40.0 0.08 ***	78.3 -0.1 ***		4.5 -0.02 *	6.2 -0.02 *	19.0 0.03 ***				4.1 0.01 *	13.3 -0.03 ***			10.1 0.02 **	15.8 -0.03 ***	
Hemi rosettes		66.0 -0.1 ***		12.1 -0.03 ***	14.5 -0.03 ***	4.3 0.02 *	6.3 -0.02 *		5.1 0.01 *	3.7 -0.01 .	20.8 -0.03 ***					
Hemi stolon	6.1 -0.03 *	38.9 -0.09 ***		52.3 -0.06 ***	6.3 -0.02 *	9.8 0.03 **	7.2 -0.02 **		2.4 -0.01		40.3 -0.05 ***			9.5 0.02 **	6.9 -0.02 **	
Therophytes	102.1 0.1 ***	73.2 0.1 ***		31.5 0.05 ***	11.1 0.03 ***	7.1 -0.02 **	3.2 0.01 .		12.2 0.03 ***	2.5 0.01	38.5 0.05 ***			12.4 -0.03 ***	16.2 0.03 ***	3.0 -0.01 .
SLA	102.5 1.4 ***	20.5 0.6 ***						2.8 -0.1 .			10.8 0.3 **	7.0 -0.2 **				
Height	291.5 -0.3 ***				3.2 0.02 .	4.7 -0.02 *	12.6 0.03 ***	2.0 0.01	2.8 -0.02 .	23.6 -0.05 ***	4.8 -0.02 *			2.8 0.01 .		7.0 0.02 **
Seed mass			3.9 0.04 *		19.3 0.09 ***	3.7 -0.04 .	53.7 0.1 ***	3.1 -0.04 .	9.0 0.06 **		3.1 -0.04 .	4.2 0.05 *				
Flowering onset	739.7 -1.1 ***	27.2 -0.2 ***	2.8 -0.04 .	5.7 -0.06 *	3.4 -0.05 .	2.0 0.04		2.7 0.04	21.3 -0.1 ***	36.3 -0.2 ***	2.6 -0.05	2.8 -0.05 .			4.1 -0.04 *	3.2 0.04 .
Flowering duration	109.7 0.1 ***	37.8 0.08 ***				2.9 -0.01 .		2.6 -0.01	3.4 0.01 .	10.3 0.03 **		9.2 -0.03 **		6.6 -0.02 *	26.2 0.04 ***	
Anemogamous	111.0 -0.1 ***	64.4 -0.08 ***	10.3 0.02 **			2.0 0.007	3.1 -0.009 .			4.7 -0.01 *	5.9 -0.01 *			6.7 0.01 *	5.6 -0.01 *	3.6 0.01 .
Auto_apo pollination	195.5 0.2 ***	7.1 0.03 **	6.9 -0.02 **	7.6 -0.02 **	12.9 -0.03 ***	3.8 0.02 .	5.6 -0.02 *		11.8 0.02 ***	36.9 0.04 ***	5.1 0.02 *				4.7 0.01 *	2.7 -0.01
Facultative entomogamous		8.9 0.03 **		14.6 0.02 ***	9.2 0.02 **	3.5 -0.01 .	9.6 0.02 **	3.7 0.01 .		2.8 -0.009 .	5.30 0.01 *				3.1 0.008 .	
Compulsory entomo-gamous	3.3 0.02 .		3.9 -0.01 *	5.0 -0.01 *			2.6 0.008	4.5 -0.01 *			7.9 -0.02 **	3.5 0.01 .			4.2 -0.01 *	2.7 -0.008
Animal dispersal	25.7 0.05 ***	14.8 -0.04 ***			8.6 0.01 **			5.4 -0.01 *	10.0 0.02 **		24.2 -0.03 ***					
Baro_autochory	69.1 -0.08 ***	8.5 0.03 **	13.6 0.02 ***	11.0 0.02 **	2.3 0.008		10.4 0.02 **		2.1 -0.008		9.0 0.02 **	8.3 -0.02 **		6.8 -0.01 **		8.0 -0.02 **
Wind dispersal	13.0 0.03 ***		8.2 -0.01 **	8.4 -0.01 **	23.9 -0.02 ***		19.9 -0.02 ***	2.8 0.008 .				6.4 0.01 *		2.7 0.008		8.0 0.01 **
Trophic level	10.2 0.1 **	22.9 0.2 ***			18.9 0.08 ***	41.2 -0.1 ***	7.3 0.05 **		2.3 0.03	5.0 0.04 *			3.0 -0.03 .	2.1 -0.03	76.5 0.1 ***	3.4 -0.03 .

Table 14: Linear models given the F_value and the estimate for the CWV traits values. A compartment in color is significant, green for the positive interactions and yellow for the negative ones. The point (.) indicated a p_value above 0.05, the stars indicated a p_value between 0.05 and 0.01 with one star (*), a p_value between 0.01 and 0.001 with two stars (**) and a p_value under 0.001 with three stars (***).

Traits/Var	Date Winter	Habitat R	V_100m	Sand	MO	CN	pH	feng	famo	nherb	wir	wsr	Ntont_ir	Ntont_sr	npm	Rainfall
SLA	67.7 9.2 ***	173.6 -14.7 ***	13.3 -2.2 ***	2.9 -1.0 .	17.7 2.5 ***				15.9 2.4 ***	26.7 -4.7 ***	7.0 -2.0 **	2.6 -1.6		10.6 -2.5 **	16.5 2.5 ***	
Height	220.1 0.6 ***	98.0 -0.4 ***	16.9 -0.09 ***		18.8 0.09 ***		2.0 0.03	4.1 -0.05 *	9.6 0.08 **	4.3 -0.06 *			3.8 0.05 .	9.0 -0.07 **	4.6 0.05 *	4.2 -0.05 *
Seed mass	34.4 0.4 ***	181.3 -1.0 ***	32.1 -0.2 ***	6.1 -0.1 *	2.8 0.08 .	9.5 0.1 **	2.5 -0.06			30.6 -0.2 ***			5.6 0.1 *	2.3 -0.06		
Flowering onset	29.1 -1.0 ***	222.8 -2.8 ***	15.5 -0.4 ***	13.2 -0.4 ***	5.7 0.3 *	3.6 0.2 .			3.7 0.2 .	39.0 -1.0 ***	10.0 -0.4 **	3.4 -0.3 .		7.3 -0.4 **	8.1 0.3 **	
Flowering duration	142.6 3.4 ***	102.6 -2.9 ***	10.9 -0.5 **	4.9 -0.3 *	11.7 0.5 ***			1.9 -0.3	22.7 0.8 ***	7.6 -0.7 **	4.9 -0.4 *	4.3 -0.5 *		13.9 -0.7 ***	30.3 -0.7 ***	
Trophic level	61.0 2.1 ***	170.8 -3.5 ***	12.0 -0.5 ***	8.1 -0.4 **	18.8 0.6 ***				21.0 0.7 ***	29.1 -0.8 ***	12.9 -0.6 ***			11.4 -0.6 ***	26.9 0.7 ***	

```r
# Fiche code R

# Replacement of missing data

library(mice)                       # mice = multivariate imputation by chained equations
trait1m <- mice(trait1)             # impute the missing data 5 times, the method use to replace the missing data depends on the
                                    # measurement level of the target column.
trait1c <- complete(trait1m)        # export imputed data

# to export a dataset from R to the computer

write.table(data, "trait_vertigo1.csv", row.names = TRUE, sep=";", dec=".") # data must be transformed in dataframe first,
                                                                            # row.names allow to keep the names of the rows,
                                                                            # sep determine the mode of separation between the columns
                                                                            # and dec represents the form of the dot

## Diversity indices calculation
# calculation of the species richness on the matrix L: species x plots

library(vegan)
S <- specnumber(MatrixL)

# calculation of the sum of abundance on the matrix L; species x plots

library(stats)
Abun <- rowSums(MatrixL)

# calculation of functional richness (FRic) and Rao' quadratic entropy (Rao)

library(FD)
Div_ind <- dbFD(MatrixQ, MatrixL1, w.abun = TRUE, stand.x = FALSE, m = 8, calc.FRic = TRUE, stand.FRic = FALSE, scale.RaoQ = FALSE,
                calc.FGR = FALSE,  calc.FDiv = TRUE, clust.type = "complete", calc.CWM = TRUE, CWM.type = "all", print.pco = FALSE)
                                    # for FRic, calc.FRic must be equal to TRUE and m must be determined,
                                    # if m is to high the function don't run
                                    # Rao is calculated by default
## Calculation of CWM and CWV

library(FD)
Div_ind <- dbFD(MatrixQ, MatrixL1, w.abun = TRUE, stand.x = FALSE, m = 8, calc.FRic = TRUE, stand.FRic = FALSE, scale.RaoQ = FALSE,
                calc.FGR = FALSE,  calc.FDiv = TRUE, clust.type = "complete", calc.CWM = TRUE, CWM.type = "all", print.pco = FALSE)
                                    # to calculate CWM, calc.CWM must be equal to TRUE and CWM.type = "all"
                                    # to obtain the proportion of the qualitative variable (example the biological type)
# calculation of CWV

CWV <- data.frame(matrix(data = NA, nrow = 101, ncol = 27))  # creation of an empty table

for (j in c(1:11))                  # loop for the traits
{
  for (k in 1:101)                  # loop for the plots
  {
    A = 0
    for (i in 1:200)                # loop for the species
    {
      A = A + (MatrixL[k,i]*((MatrixQ1[i,j])-(CWM[k,j]))^2)  # variance formula with the matrix L: species x plots
                                                             # the matrix Q: traits x species and CWM obtain above with FD package
    }
    CWV[k,j] <- A
  }
}
```

```r
# Performing a Hill & Smith analyses (for qualitative and quatitative variables)

library(ade4)
HS <- dudi.hillsmith(df = MatrixQ)                          # Hill & Smith was dispayed and the number of kept axes asked
HS <- dudi.hillsmith(df = MatrixQ, scannf = FALSE, nf = 4)  # Hill & Smith performed on the matrix of traits and 4 axes were kept

# return the inertia of Hill & Smith

inertie <- inertia.dudi(HS,col.inertia=TRUE)

# Display supplementary variables

library(vegan)
env.fidelity <- envfit(HS, Fidelity_Index$Fidelity.Index)

# Display analyses

s.label(coord_traits_quali,clabel=0.8, boxes=FALSE)                      # only names
s.arrow(coord_traits_qt[,1:2],clabel=0.8, boxes = FALSE, add.plot=TRUE)  # with arrows, add.plot = TRUE allow the addition
                                                                         # with the previous one
s.class(HS$li,trait$Grime)                                               # display groups: first coordinates, second type of groups

# Spearman test

cor.test(Fidelity_Index[,1], Fidelity_Index$Fidelity.Index)    # give the correlation between the traits and the fidelity index

# Test  no parametric Kruskal Wallis and post-hoc: Dunn test

library(dunn.test)
kruskal.test(HF$li$Axis1~trait$Grime)                          # coordinates of the axis one in function of (~) a variable
dunn.test(HF$li$Axis1,trait$Grime)

# linear model with interaction

library(car)
library(MASS)

model <- lm(diversity[,1] ~ R_IR*Certification, data = ab1)    # the * indicated the interaction of both factors
```

```r
# Calculation of best model with the AIC method

models <- lm(diversity[,1] ~ date + Area + V_100m + Sand  + MO + CN + pH_water + feng + famo + nherb + wir
             + wsr + ntont_ir + ntont_sr + npm + Rainfall, data=Ps1)
smod <- stepAIC(models)

# ANOVA, type III: for the model with interaction

Anova <- Anova(model, type = 3)

Shapiro <- shapiro.test(residuals(model)) # Test to ensure the normal distribution of the residuals of the ANOVA
vif <- vif(model)                         # Test the colinearity between the variables in a model

# glht function to know if the variable is significant and in with way is the difference

library(multcomp)
glht(model, linfct = mcp(R_IR = "Tukey"))  # general linear hypotheses, for parametric model, refers to null hypotheses
                                           # and return the estimate of the model
                                           # Tukey post_hoc test because it is a parametric one*
```

```r
# Algorithm to determine the best number of groups: Mantel Statistic

library(ape)

grpdist <- function(X)
{
  require(cluster)
  gr <- as.data.frame(as.factor(X))
  distgr <- daisy(gr,"gower")
  distgr
}

#Run based on the Ward clustering
kt <- data.frame(k=1:nrow(practices), r=0)

for(i in 2:(nrow(practices)-1)) {
  gr <- cutree(clust.pca, i)
  distgr <- grpdist(gr)
  mt <- cor(dist.pca,distgr, method="pearson")
  kt[i,2] <- mt
}
kt
k.best <- which.max(kt$r)

#Plot

plot(kt$k, kt$r, type="h", main="Mantel-optimal number of clusters-Ward", xlab="k (number of groups)", ylab="Pearson's correlation")
axis(1, k.best, paste("optimum", k.best, sep="\n"), col="red", font=2, col.axis="red")
points(k.best, max(kt$r), pch=16, col="red", cex=1.5)

# PCA : Principal Component Analysis

library(ade4)
pca_practices <- dudi.pca(df = R3_pra)
pca_practices <- dudi.pca(df = R3_pra, scannf = FALSE, nf = 3)

# HCA: Hierarchical cluster analysis

library(FactoMineR)
dist.pca <- dist(pca_practices$li, method="euclidean") # calculation of euclidean distance between the individual of the PCA
clust.pca <- hclust(dist.pca, method="ward.D2")        # dendrogram calculation, ward D2 as method because:
                                                       # The Ward's method consists in aggregating two clusters such that the growth
                                                       # of within-inertiais minimum.

# Calculation of significant difference between modality of a model

library(phia)
testInteractions(model, pairwise = "group$group", fixed = "R_IR")

# RLQ - 4th corner analyses (Dray et al., 2014)

library(ade4)

afc.L1 <- dudi.coa(L1)                              # AFC on sqrt-transformed matrix L: species x plots
HS.Q <- dudi.hillsmith(Q1, row.w = afc.L1$cw)       # Hill and Smith on matrix Q: traits x species, scaled on AFC coodinates
pca.R <- dudi.pca(R.var, row.w = afc.L1$lw)         # PCA on the environmental variables and management practices

RLQ <- rlq(pca.R, afc.L1, HS.Q)                     # RLQ analysis


nrepet <- 9999
four.comb.rlq <- fourthcorner(R.var, L1, Q1, modeltype = 6, p.adjust.method.G = "none", # fourth corner analysis
                              p.adjust.method.D = "none", nrepet = nrepet)

four.comb.rlq.adj <- p.adjust.4thcorner(four.comb.rlq,p.adjust.method.G = "fdr", p.adjust.method.D = "fdr")
                                                    # adjustment of 4th corner with only the correlation with p_value < 0.05.
testrlq.rlq <- randtest(RLQ, modeltype = 6, nrepet = nrepet) # to be sure that the model is significant

testQaxes.comb.rlq <- fourthcorner.rlq(RLQ, modeltype = 6, typetest = "Q.axes", nrepet = nrepet, # combination of RLQ and 4th corner
                                       p.adjust.method.G = "fdr", p.adjust.method.D = "fdr")
testRaxes.comb.rlq <- fourthcorner.rlq(RLQ, modeltype = 6, typetest = "R.axes", nrepet = nrepet,
                                       p.adjust.method.G = "fdr", p.adjust.method.D = "fdr")
```

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Titre français : Les traits de réponse de la flore adventices permettent-ils de comprendre l'impact des pratiques agricoles dans les vignobles ?

Titre anglais: Can the traits help us understanding the response of weed flora to viticultural practices?

Abstract: The aim of this study was to understand the impact of viticultural practices on weed flora using a trait-based approach, to help winegrowers managing the weeds in an environmentally friendly way without economic losses. The study takes place in 101 Bordeaux vineyards plots, where floristic samples have been made twice (April, June 2015) in two distinct areas (rows, inter-rows). Statistical analyses have been performed to test the relationships between species trait values, environmental variables (weather, soil properties, landscape) and management practices, using linear models, and multivariate analyses (RLQ – fourth corner analyses). Three approaches have been developed at different levels of management practices (using either organic versus conventional, homogeneous groups of plots with similar management systems based on a multivariate classification of raw variables, or directly the raw variables). First, the results showed a difference in the Grime CSR strategies along a gradient of disturbance. In disturbed areas (on the rows and where herbicides and/or tillage was applied), a convergence of trait values of weeds was observed with a ruderal strategy, characterized by an annual life cycle, an auto-apogamous reproduction and a baro-autochory dispersal. In less disturbed areas (on the inter-rows and were mowing was applied), the range of trait values of weeds was higher and they harbor a competitive strategy characterized by a pluri-annual life cycle (hemicryptophytes), an entomogamous pollination and an animal dispersal. To a lesser extent, an influence of the resource gradient was also highlighted with more competitive species (higher seed mass and stature) found on richer soils (higher soil pH). The clustering of groups with similar management practices appeared as a good compromise to understand patterns and to communicate towards winegrowers.

Key Words: Bordeaux vineyards, *Vitis vinifera*, management practices, tillage, mowing, herbicide treatment, taxonomic and functional diversity, trait- based approach.

Résumé : Le but de cette étude était de comprendre l'impact des pratiques viticoles sur la flore adventice en utilisant l'approche fonctionnelle des traits, afin d'aider les viticulteurs à gérer les adventices tout en respectant l'environnement et sans pertes économiques. L'étude se déroule à Bordeaux sur 101 parcelles où des relevés floristiques ont été effectués deux fois (Avril, Juin 2015) dans deux zones (rangs, inter-rangs). Les analyses statistiques effectuées testent les relations entre les traits des espèces, les variables environnementales (météo, sol, paysage) et les pratiques agricoles, utilisant des modèles linéaires et des analyses multivariées (RLQ – 4th corner). Trois approches ont été développées à différents niveaux de pratiques (une gestion soit biologique, soit conventionnelle, des groupes homogènes de parcelles basés sur la classification des pratiques, ou à partir des pratiques brutes). Premièrement, les résultats ont montré une différence de stratégies de Grime CSR suivant un gradient de perturbation. Dans les zones très perturbées (le rang et les zones d'application du labour ou des herbicides), une convergence des traits a été observée avec une stratégie rudérale caractérisée par un cycle de vie annuel, une reproduction auto-apogame et une dispersion baro-autochore. Dans les zones peu perturbées (inter-rangs, zones d'application de la tonte), la gamme de traits était plus importante et adoptait une stratégie compétitrice caractérisée par un cycle de vie pluriannuel (hémicryptophytes), une pollinisation entomogame et une dispersion zoochore. De manière moins marquée, une influence du gradient de ressources a été mis en avant avec des espèces très compétitrices (importante masse de graines et hauteur) trouvées sur des sols riches (pH plus élevé). La mise en place de groupes ayant les mêmes pratiques apparaitrait être un bon compromis pour comprendre les modèles et communiquer avec les viticulteurs.

Mots clés : vignobles bordelais, Vitis vinifera, pratiques viticoles, labour, tonte, herbicides, diversités taxonomique et fonctionnelle, approche fonctionnelle des traits.