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Drivers of weed diversity on patch and pattern scale in vineyards of Kosovo

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Vineyards in the municipality of Rahovec
(photo taken during data sampling in May 2016)

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Dedicated to my dear family:

Babi, Nani, Tina, Rudinë and Latif.

I am deeply thankful for your love, support, and sacrifices.

You all kept me focused on my end goal.

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Abbreviations

AMP	the range in degrees Celsius between HIGH and LOW
DCA	Detrended Correspondence Analysis
DIN	stands for "Deutsches Institut für Normung", meaning "German institute for standardisation"
EU	European Union
FAO	Food and Agriculture Organisation
GIZ	Gesellschaft für Internationale Zusammenarbeit
HIGH	the highest constant temperature with a germination rate of at least 5%;
IDE	integrated development environment
ISO	International Organization for Standardization
IVM	Indicator Value Method
KAS	Kosovo Agency of Statistics
KEC	Kosovo Energy Corporation
LOPT	the optimal temperature for germination
LOW	the lowest constant temperature with a germination rate of at least 5%;
MBPZHR	Ministria e Bujqësisë, pylltarisë dhe zhvillimit rural
MHL	million Hectoliter; HL: a metric unit of volume equal to 100 liters
PC-ORD	software that performs multivariate analysis of ecological data entered in spreadsheets
pH	soil acidity
SOM	soil organic matter
TIVM	Total Indicator Value Method can play several roles in community classification
USAID	United States Agency for International Development

Summary

The PhD thesis provides data on the vineyard weed flora and vegetation in Kosovo, especially in the well-known wine-growing regions Rahovec and Suhareka. The data collected and analyzed are important in two ways: On the one hand, they contribute to reducing knowledge gaps on biodiversity and its drivers in Kosovo. Furthermore, the study can help regional agriculture to implement weed management strategies adapted to the species and vegetation that are present.

The investigation methods include **(A)** field surveys of the weed flora and vegetation and **(B)** soil chemical analysis in cultivated fields of the study areas, **(C)** germination experiments in climate chambers, and **(D)** germination experiments under field conditions. In the germination experiments, four weed species occurring in the two study regions were investigated. The field survey and the field experiments were conducted in Kosovo, the germination experiments in climate chambers at the University of Giessen.

In May to August 2016 and 2017, the weed flora and vegetation was documented on a total number of 70 vineyard patches (35 patches in Rahovec; 35 patches in Suhareka) **(A)**. On each of the 70 patches, four plots were selected randomly for detailed vegetation sampling. Each of the plots was divided into two subplots ‘within’ and ‘between rows of vines’ with a standard size of 1 m x 5 m. To avoid edge effects, the minimum distance of each subplot to the patch border was 5 m. For each subplot vegetation relevés were compiled. For each subplot, additional site data was documented in the field and derived from maps (height above sea level, exposition, aspect, northness, eastness). Based on interviews with the farmers who cultivated the patches, additional information was compiled for each of the 70 patches on herbicide use. This made it possible to distinguish between two management types (with versus without herbicide use) in the data analysis.

On each of the subplots soil sampling (soil depth: 5-15 cm) was carried out **(B)**. In each subplot, the soil of three sub-samples that were taken with a hand auger was mixed. Each of the mixed soil samples was dried at room temperature and sieved (to exclude stones with a size >2 mm from further soil analysis and to quantify the stone content of the soils) before the chemical analysis. Soil pH was measured in both $H_2O_{dest.}$ and $CaCl_2$. The total amount of organic matter (OM) was determined by the ignition method. The amount of plant-available P and K was

quantified with the help of the Ammonium lactate method.

The vegetation and land management data and the soil data were considered in ordinations and indicator species analysis to relate the diversity of the weed vegetation to the considered management practices and site conditions.

For four selected weed species (*Amaranthus retroflexus, Chenopodium album*, *Echinochloa crus-galli, Solanum nigrum*) relations between air temperature and germination were analyzed in climate chambers **(C)**. The seeds were sampled on the patches that were investigated in 2016. The germination experiment was conducted with seeds of the F1-generation of the sampled seeds. The germination succeed was tested for different temperatures ranging from 3 °C to 30 °C. Five replicates with a standard number of 50 seeds per species and temperature level were analyzed. The germination experiment lasted for 12 weeks in winter 2017/18. In addition to the climate chamber experiment, relations between air temperature and germination were studied under field conditions **(D)**. As described before, seeds of the F1-generation of the sampled seeds were also used in the field experiment in 2018. In standardized plots (30 cm x 30 cm) with heat-sterilized soil (to prevent germination of seeds that may occur in the soil) a standardized number of 200 seeds of the selected weed species was investigated by means of weekly recordings within the entire vegetation period. In these recordings the number of germinated seeds was documented. For each of the selected species, three replicates were studied to allow statistical analysis of the data. To relate the germination data to the air temperature during the vegetation period the minimal and maximal air temperature next to the plots was recorded daily.

Overall 84 weed species were recorded during 2016 and 2017 in the two study regions. In both years, the species number was higher in Suhareca region. The species numbers and weed coverage differed considerably between the two regions and management types. Fields without herbicide application in Suhareka region had significantly more species than herbicide-treated ones in Rahovec region. The DCA analysis and the indicator species analysis prove remarkable differences in the weed composition and coverage between the study regions, management types and the small-scale differences within and between the rows of vines in 2016 and 2017. Also the indicator species analysis resulted in differences between the two study regions, management practices and the situation within or between rows of vines.

The mean pH value in $H_2O_{dest.}$ and the mean amount of OM were higher in Suhareka

compared to Rahovec region, and the mean amount of OM was higher within compared to between rows in both regions. Moreover, the DCA analysis showed a correlation between the vegetation and soil chemical parameters.

The germination experiments in climate chambers and in the field resulted in species specific germination behavior and in differences in the germination rates between the two study regions. There were significant differences between regions at the different temperatures regarding germination of F1 seed of *Amaranthus retroflexus* and *Chenopodium album*. Moreover, *Echinochloa crus-galli, Chenopodium album* and *Solanum nigrum* achieved higher germination rates from seeds collected in the Suhareka region.

The summarized results can be interpreted in several ways: The current diversity of the vegetation in the studied vineyards is generally low due to implemented weed control measures. However, At the patch scale, the land-use intensity (with versus without herbicide application; lower intensity 'within rows' than 'between rows') is a driver of vegetation diversity, while at the pattern scale, differences in land-use intensity between the two study regions and also differences in soil chemical characteristics affect vegetation diversity.

The region-dependent differences in temperature-dependent germination rates found in the germination experiments with the F1 generation of selected weed species indicate genetic differences between the populations studied. Since both regions are not far from each other within Kosovo, these differences could be a consequence of different intensities of cultivation in both regions and resulting genetic differences of the populations.

The results are discussed with recommendations for a more sustainable use of the wine growing areas of Kosovo in the future. Options for organic management and future soil management with plant cover are presented in regard to their importance for ecosystem services and biodiversity protection.

Zusammenfassung

Die Dissertation liefert Daten über die Wilkrautflora und -vegetation der Weinberge im Kosovo, insbesondere in den bekannten Weinbaugebieten Rahovec und Suhareka. Die gesammelten und analysierten Daten sind in zweierlei Hinsicht wichtig: Zum einen tragen die Daten dazu bei, Wissenslücken über die biologische Vielfalt und ihrer Steuergrößen im Kosovo zu verringern. Zum anderen kann die Studie der regionalen Landwirtschaft bei Umsetzung von Unkrautbekämpfungsstrategien unterstützen, die an die vorhandenen Arten und die Vegetation angepasst sind.

Die Untersuchungsmethoden umfassen (**A**) Felduntersuchungen der Wildkrautflora und -vegetation sowie (**B**) bodenchemische Analysen auf bewirtschafteten Feldern der Untersuchungsgebiete, (**C**) Keimungsversuche in Klimakammern und (**D**) Keimungsversuche unter Feldbedingungen. In den Keimungsexperimenten wurden vier in beiden Untersuchungsregionen vorkommende Wildkrautarten untersucht. Die Felderhebung und die Feldversuche wurden im Kosovo durchgeführt, die Keimungsversuche in Klimakammern an der Universität Gießen.

Von Mai bis August 2016 und 2017 wurde die Wildkrautflora und -vegetation auf insgesamt 70 Weinbergsparzellen (35 Parzellen in Rahovec; 35 Parzellen in Suhareka) dokumentiert (**A**). Auf jeder der 70 Parzellen wurden vier Plots nach dem Zufallsprinzip für eine detaillierte Vegetationserhebung ausgewählt. Jeder Plot wurde in zwei Teilplots "innerhalb" und "zwischen den Rebzeilen" mit einer Standardgröße von je 1 m x 5 m unterteilt. Um Randeffekte zu vermeiden, betrug der Mindestabstand jeder Unterparzelle zur Parzellengrenze 5 m. Für jeden Teilplot wurden in den Jahren 2016 und 2017 Vegetationsaufnahmen erhoben und es wurden zusätzliche Standortdaten im Feld dokumentiert und aus Karten abgeleitet (Höhe über dem Meeresspiegel, Exposition, Aspekt, Nothness, Eastness). Auf der Grundlage von Gesprächen mit den Landwirten, die die 70 Parzellen bewirtschafteten, wurde jede der Parzellen einem Bewirtschaftstyp ‘mit’ bzw. ‘ohne Herbizideinsatz’ zugeordnet.

Auf jedem Subplot wurden Bodenproben (Bodentiefe: 5-15 cm) entnommen (**B**). Dabei wurde auf jedem Subplot mit einem Handbohrer drei Proben entnommen und gemischt. Die

Mischproben wurde bei Raumtemperatur getrocknet und gesiebt (um Steine mit einer Größe von mehr als 2 mm von der weiteren Bodenanalyse auszuschließen und den Steingehalt der Böden zu quantifizieren), bevor die chemische Analyse durchgeführt wurde. Der pH-Wert des Bodens wurde sowohl in $H_2O_{dest.}$ als auch in $CaCl_2$ gemessen. Der Gesamtgehalt an organischer Substanz (OM) wurde mit der Glühverlustmethode bestimmt. Die Menge an pflanzenverfügbarem P und K wurde mit Hilfe der Ammoniumlactatmethode quantifiziert.

Die Vegetations- und Landbewirtschaftungsdaten und die Bodendaten wurden in Ordinations- und Indikatorartenanalysen berücksichtigt, um die Vielfalt der Wildkrautvegetation mit den berücksichtigten Bewirtschaftungsmethoden und Standortbedingungen in Beziehung zu setzen.

Für vier ausgewählte Wildkrautarten (*Amaranthus retroflexus, Chenopodium album, Echinochloa crus-galli, Solanum nigrum)* wurden die Beziehungen zwischen Lufttemperatur und Keimung in Klimakammern (**C**) analysiert. Die Samen wurden auf den Flächen entnommen, die 2016 untersucht worden waren. Das Keimungsexperiment wurde mit Samen der F1-Generation der beprobten Samen durchgeführt. Der Keimungserfolg wurde bei verschiedenen Temperaturen zwischen 3 °C und 30 °C getestet. Es wurden fünf Wiederholungen mit einer Standardanzahl von 50 Samen pro Art und Temperaturniveau analysiert. Das Keimungsexperiment dauerte 12 Wochen im Winter 2017/18. Zusätzlich zum Klimakammerexperiment wurde der Zusammenhang zwischen Lufttemperatur und Keimung unter Feldbedingungen analysiert (**D**). Auch im Feldversuch im Jahr 2018 wurden Samen der F1-Generation der beprobten Samen verwendet. In standardisierten Parzellen (30 cm x 30 cm) mit hitzesterilisiertem Boden (um eine mögliche Keimung von Samen im Boden zu verhindern) wurde eine standardisierte Anzahl von 200 Samen der ausgewählten Unkrautarten durch wöchentliche Aufzeichnungen während der gesamten Vegetationsperiode untersucht. Bei diesen Aufzeichnungen wurde die Anzahl der gekeimten Samen dokumentiert. Für jede der ausgewählten Arten wurden drei Wiederholungen untersucht, um eine statistische Auswertung der Daten zu ermöglichen. Um die Keimungsdaten mit der Lufttemperatur während der Vegetationsperiode in Beziehung zu setzen, wurde täglich die minimale und maximale Lufttemperatur neben den Parzellen aufgezeichnet.

In den Jahren 2016 und 2017 wurden in den beiden Untersuchungsregionen insgesamt 84 Wildkrautarten erfasst. In beiden Jahren war die Anzahl der Arten in der Region Suhareca höher.

Die Artenzahl und die Wildkrautbedeckung unterschieden sich zwischen den beiden Regionen und Bewirtschaftungsarten. Felder ohne Herbizideinsatz in der Region Suhareka wiesen deutlich mehr Arten auf als die mit Herbiziden behandelten Felder in der Region Rahovec. Die DCA-Analyse und die Analyse der Indikatorarten belegen deutliche Unterschiede in der Wildkrautzusammensetzung und -bedeckung zwischen den Untersuchungsregionen und Bewirtschaftungsarten sowie kleinäumige Unterschiede innerhalb und zwischen den Rebzeilen in den Jahren 2016 und 2017. Auch die Indikatorartenanalyse ergab Unterschiede zwischen den beiden Untersuchungsregionen, den Bewirtschaftungsmethoden und der Situation innerhalb bzw. zwischen den Rebzeilen.

Der mittlere pH-Wert in $H_2O_{dest.}$ und die mittlere Menge an OM waren in der Region Suhareka höher, und die mittlere Menge an OM war innerhalb der Rebzeilen höher. Außerdem zeigte die DCA-Analyse eine Korrelation zwischen der Vegetation und bodenchemischen Parametern.

Die Keimungsversuche in Klimakammern und im Freiland belegen artspezifische Ergebnisse und Unterschiede in den Keimungsraten zwischen den beiden Untersuchungsregionen. Bei der Keimung von F1-Samen von *Amaranthus retroflexus* und *Chenopodium album* gab es signifikante Unterschiede zwischen den Regionen und den verschiedenen Temperaturen. Bei *Echinochloa crus-galli, Chenopodium album* und *Solanum nigrum* wurde bei den in der Region Suhareka gesammelten Samen eine höhere Keimungsrate festgestellt.

Die zusammengefassten Ergebnisse können in mehrfacher Weise interpretiert werden: Die derzeitige Vielfalt der Vegetation in den untersuchten Weinbergen ist aufgrund der durchgeführten Wildkrautbekämpfungsmaßnahmen generell gering. Die Ergebnisse lassen erkennen, dass auf der Habitat-Ebene die Nutzungsintensität (mit versus ohne Herbizidanwendung; geringere Intensität "in den Reihen" als "zwischen den Reihen") als Treiber der Vielfalt der Vegetation wirkt, während auf der Landschafts-Ebene Unterschiede in der Nutzungsintensität zwischen den beiden Untersuchungsregionen und auch Unterschiede der chemischen Bodeneigenschaften auf die Vielfalt der Vegetation wirken.

Die in den Keimungsexperimenten mit der F1-Generation von ausgewählten Wildkrautarten gefundenen regionsabhängigen Unterschiede bei temperaturabhängigen Keimungsraten deuten auf genetische Unterschiede zwischen den untersuchten Populationen hin.

Da beide Regionen innerhalb des Kosovo nicht weit voneinander entfernt liegen, könnten diese Unterschiede eine Folge der unterschiedlich intensiven Bewirtschaftung in beiden Gebieten und daraus resultierende genetische Unterschiede der Populationen sein.

Die Ergebnisse werden mit Empfehlungen zu einer künftig nachhaltigeren Nutzung der Weinbaugebiete des Kosovos diskutiert. Dabei werden Optionen der organischen Bewirtschaftung und eines künftigen Bodenamagements mit Begrünung hinsichtlich ihrer Bedeutung für Ökosystemdienstleistungen und den Schutz der Biodiversität vorgestellt.

1. Introduction

Agriculture is one of the most important sources of human survival, but also one of the sectors with the strongest impact on the environment, being at the same time among the most responsible and the main victims of the environmental crisis (Acampora et al. 2018). Worldwide and since long time, agricultural land use has shaped and altered the majority of our planet's landscapes (Foley et al. 2005) and severely impacted biodiversity, ecosystem functioning, and multiple ecosystem services (ES) in agricultural ecosystems (Allan et al. 2015, Foley et al. 2005). In agroecosystems species diversity is determined by the interactions that develop among crops and weeds, and the environment including the land-use practices they both share (Radosvich 1984). As agroecosystems harbor one of the largest parts of terrestrial biodiversity worldwide, biodiversity conservation efforts should focus on the identification and conservation of sustainable land-use practices (Tscharntke et al. 2012).

Agricultural practices produce significant amounts of greenhouse gases, which is one of the main causes of climate change. At the same time, the sector suffers the negative impacts of climate change, in terms of productivity decrease and increased risks related to food safety (Acampora et al. 2018). Moreover, agricultural intensification has had negative effects on biodiversity such as the diversity of arable weed communities (Pinke et al. 2009, Storkey et al. 2012, Brütting et al. 2012) providing conservation and aesthetic value, and a wide variety of ecological services (Altieri 1999, Marshall et al. 2003, Barberi et al. 2010). Weeds are considered any species, competing with crops for water, space, light, and nutrition. However, weeds can also draw pests away from crops, provide habitat and resources for biological pest control (Norris and Kogan 2005), for pollinator species to provide crop pollination (Carvalheiro et al. 2011), and for many other faunal species groups (Marshall et al. 2003). All this also applies to vineyards, as one of the most intensively managed agroecosystems with numerous pesticide applications, soil tillage operations and high landscape simplification (Nicholls et al. 2008).

Vitis vinifera (grapevine) is one of the most economically important fruit crops, and it is largely used for both fresh consumption and wine (FAO 2012), likely first domesticated from the wild grapevine (*V. vinifera subsp. sylvestris* (C.C.Gmel.) Hegi) in today's regions of Georgia, Armenia, and Azerbaijan about 8,000 years ago (Myles et al. 2011). Globally, vineyards cover a total area of over 7 million hectares (The Wine Institute 2012). Based on information collected on

30 countries, which in 2019 represented 84% of the world production, world wine production (excluding juices and musts) is estimated between 254 and 262 MHL in 2020, with a mid-range estimate at 258 MHL (International Organisation of Vine and Wine 2020). In Europe, the grapevine, *Vitis vinifera* L., is traditionally planted in warm and relatively dry areas of the central part of the continent. In the European Union (EU), suitable weather conditions favored a good harvest in 2020. The production volume is estimated at 159.0 MHL (excluding juices and musts), about 5% more than in 2019.

Due to human migration routes during several thousand years, wine cultivars were spread around the Mediterranean and Balkan countries (This et al. 2006). By trading activities, ancient Greeks have spread grape varieties from the Western side of the Balkans and the Adriatic islands (This et al. 2006, Štajner et al. 2014) and gradually, Illyrians and other native populations replaced the consumption of honey and cereal-based beverages such as mead and beer with wine (Pilipovic 2013). Regional grape varieties like Plavac Mali, Zelenac, and Vranac are grown in most of the Balkan countries (Robinson et.al 2012). Kosovo is one of the known countries in the Balkans for grapevine cultivation since antiquity, and this tradition is mainly concentrated in the Dukagjini Plain, especially in the provinces of Rahovec (70%) and Suhareka (21%) (MAFRD 2011). Smederevka, Vranac, Game e Thjeshtë, Prokupac, Italian Muskat, Muscat of Hamburg, and Italian Riesling are the main cultivars, representing approximately 80% of the total national grapevine crops. About 3,436 hectares are planted with vineyards in Kosovo, of which 2,525 ha are cultivated for wine and 911 ha for table grapes (KAS 2020). However, in recent times these areas are increasing, especially with table grapes, as a result of market demand and economic profitability of the production. Changes in food production systems over the last 50 years have transformed traditional European agricultural landscapes and also the vineyards in Kosovo.

Not only the area under vine, but also the management in viticulture has changed in recent decades, with management becoming increasingly intensive in many regions worldwide (Paiola et al. 2020). In general, vineyard management depends on several factors such as climate, water availability, soil type, grapevine variety, agri-environmental policies, and most importantly winegrowers' knowledge in weed and pest management practices (Winter et al. 2018). Besides other measures such as variety selection or professional pruning of grapevines, weed management in vineyards intensifies the establishment of grapevines and improves growth and vine production.

Weeds compete with grapevines for water and nutrients, space and light (Ingels et al. 2005), causing reductions of yield by up to 37% and of cane weight by 68% (Byrne and Howell 1978). Moreover, weeds can reduce crop yields through allelopathy (Mohler 2001) and hosting arthropod pests and plant pathogens such as plant-parasitic nematodes (Bendixen 1986, Anwar et al. 1992). On the other hand, weeds may have many beneficial effects on the agroecosystem. Many ecosystem services of particular importance for agriculture such as pollination and natural pest control often depend on the number of species in an ecosystem (Tilman et al. 2002). Thus, the impoverishment of natural communities by agriculture should be minimized to reduce negative feedback on production. Consequently, adequate weed management at an intermediate level has a positive impact on agriculture sustainability, intensifies agroecosystem productivity, and also improves ecological services (Gerowitt et al. 2003).

The weeds that grow in vineyards all over the world are extremely diverse given the wide range in e.g. soil, climatic and topographic conditions and cultivation practices to which they are subject. Studies on vineyard adventitious flora are therefore required for each vine-growing area and, consequently, many authors studied and characterized the weeds associated with grapevine cultivation mainly at regional scales (e.g., Beuret 1981, Espirito-Santo et al. 1990, Guillerm 1990, Wilmanns 1989, 1990, 1999, Zaragoza-Larios 1990, Bujan 1991, Lete-Vela 1998, Afonso et al. 2001, Villarias et al. 2001, Gago et al. 2007). Despite all the regional differences, the weed vegetation in vineyards is also characterized by a number of common characteristics: Vineyard weed communities are formed of species adapted to the life cycle of the grapevine and human interventions in the crop (Eliá 1983). Many weeds of the vineyards are short-lived species and adapted to development in partial shade with only moderate water availability. Some perennial weeds in vineyards such as *Allium vineale* and several species of the genus *Muscari* have bulbs to survive summer drought.

In the past, effects of agricultural practices on weed infestation in perennial agroecosystems like vineyards were neglected compared with annual cropping systems (e.g., Buhler et al. 1995, Clements et al. 1996, Légère et al. 2005, Moonen and Barberi 2004, Baumgartner et al. 2007, 2008, Gago et al. 2007), and also today, weed management practices in vineyards are mainly focused on controlling weeds 'within rows' of the vine stocks. Comparable to an intercropped system, the area 'between the rows', the alley, often supports a perennial cover crop or spontaneous weed vegetation to reduce soil erosion and enhance soil organic matter. Nevertheless, today's vineyards are among the most intensive forms of agriculture often resulting in simplified landscapes, where semi-natural vegetation is restricted to scattered habitats in a matrix of species-poor managed patches. High levels of disturbance by agricultural management practices such as digging the soil and applying fertilizer and pesticides usually have a negative impact on biodiversity within a vineyard (Donald et al. 2000, Tilman et al. 2001, Benton et al. 2002, Robinson and Sutherland 2002, MEA 2005). Therefore today's vineyard vegetation is often species poor both at the landscape or regional scale (pattern scale) and within individual vineyard habitats (patch scale). No comprehensive data are available on current biodiversity in wine-growing regions of Kosovo, either for patch nor for pattern scale. Reducing this knowledge gap is the main objective of the research presented here.

Research on the biodiversity in vineyards of Kosovo is also important against the background that the country is known as a biodiversity hotspot in Europe (Myers et al. 2000) with many steno endemic, endemic, rare, important but also endangered, threatened, and vulnerable plant and animal species. Kosovo therefore has a strong responsibility for the country's biodiversity and is making numerous efforts to improve the data base and protect biodiversity (GIZ 2017). In terms of designation of protected areas, during the past years in Kosovo, even though important steps, including legislation, have been undertaken. However, biodiversity still does not receive enough attention in terms of data collection, data reporting and management, and creation of an effective legal basis for obligatory data flow. Moreover, in practice, the importance of stakeholder coordination has not been adequately addressed so far, even though as an issue it has been tackled in several strategic documents, most lately in the Strategy and Action Plan for Biodiversity 2011-2020 aiming at integrated sectoral policies, effective management and sustainable use of biodiversity in close cooperation with relevant stakeholders (GIZ 2017). According to GIZ, governmental strategic documents identified several important areas in the process of effective biodiversity information management and reporting including clarification of institutional competencies and advancement of cooperation between academic institutions, the governmental and non-governmental sector in mapping and identifying biodiversity values, as well as creation and proper functioning of databases aiming at registering and monitoring biodiversity values and associated impacting activities. According to many documents about biodiversity and environmental protection, tailored activities are urgently needed. But so far, the lack of inventory or monitoring of biodiversity and the environment in Kosovo, is mainly counteracted through smaller projects or individual scientific studies.

Goals of the study

The goals of this study are

i. to provide information about the frequency and abundance of weeds within vineyards *(patch scale)* in the regions of Rahovec and Suhareka, located in the western part of Kosovo, and to quantify the differences between the two regions (*pattern scale*),

ii. to analyze relationships between the weed vegetation, natural site conditions and management practices, i.e. to identify drivers of weed diversity, on patch and pattern scale,

iii. to characterize the germination behavior of selected weed species in the two study regions and to identify potential region specific differences,

iv. to discuss the results with regard to biodiversity conservation and to identify options for sustainable viticulture in the future.

2. Kosovo and the study regions Rahovec and Suhareka

2.1 Kosovo: Location, climate, soils, biodiversity land use and societal frame

2.1.1 Geographic location, topography and water network of Kosovo

The Republic of Kosovo is located in the south-eastern part of Europe, on the border with Albania in the south-west, Montenegro in the north-west, Serbia in the north-east and Northern Macedonia in the south. Kosovo is divided into 38 municipalities. The capital of Kosovo is Prishtina. Kosovo has a central geographic position on the Balkan Peninsula and extends between 41°51' and 43°16' and within the geographic length 19' 59' and 21°47'. The land of the Republic of Kosovo is characterized by different altitudes. The lowest point in Kosovo at 270 m a.s.l. is located in the valley of the Drini i Bardhë River, and the highest point, the mountain Gjeravica, reaches 2,656 m a.s.l. Both locations are in the west of Kosovo not far from the border with Albania. With regard to hydrography, Kosovo is divided into several river basins: the Drini i Bardhë (White Drini), Ibri, Morava e Binçës and Lepeneci (KAS 2019).

2.1.2 Climate and soils of Kosovo

The climate of the Republic of Kosovo is mostly continental, i.e. characterized by warm and relatively dry summers and cold winters, with Mediterranean influences in the western part of the country. The average air temperature within the country varies from +30°C in summer to -10°C in winter. Kosovo has on average 160 rainy days a year. Table 1 shows the annual precipitation in two main climate areas in the lowlands of Kosovo, the Kosovo plain in the east and the Dukagjini plain in the west, in 2015-2019 (KAS 2020), highlighting a wide range of values between the areas and years from 562 to 949 mm, and on average higher precipitation in the west of the country. However, due to uneven elevations in the country, there are wide ranges in temperature and precipitation values within both climate areas (KAS 2019).

Table 1: Climate areas of Kosovo and annual precipitation in 2015-2019

Climate area	2015	2016	2017	2018	2019	X̄ 2015-2019
			(mm)			
Valley of Kosovo	697	754	592	711	562	663
Valley of Dukagjini	684	949	701	853	697	777

Data source: KAS (2020) and self-calculated mean values

According to Drezgić (1957), Babović (1957), Ivović and Mijović (1969) and a digital map of soil types (scale 1:50 000) provided by the Institute of Soil Sciences of the University of Prishtina (Elezi et al. 2004) and referring to the WRB-soil classification (IUSS WorkingGroup WRB 2015) dystric (26%) and eutric cambisols (21 %) cover nearly half of the total area of Kosovo. Vertisols (10%) cover considerable areas in several municipalities including Rahovec and fluvisols (8%) are predominant along the rivers. Smaller area shares are characterized by lithosols, pseudogleys, terra rossa, calcaric cambisols, calcaric luvisols, rendzinas, rankers and others. The larger part of the agricultural soils is generally nutrient-rich and represents a suitable growth medium for natural plants and crops. As in general, also in Kosovo areas with carbonate-rich soils are particularly favorable for high plant species diversity (Gashi 1985, Zajmi 1996, Gashi and Spaho 2002).

Irrigation and soil alteration by agricultural use are crucial factors that have impacted the pedogenetic process for several thousand years. Moreover, the soils of several areas in Kosovo are degraded from former mining activities. As a consequence, some authors report high levels of heavy metals in areas near to former mines (Borgna et al. 2009, Nanoni et al. 2011, Šajn et al. 2013, Zogaj et al. 2014), which considerably exceeded the permitted values for agricultural soils regarding EU standards.

2.1.3 Biodiversity of Kosovo

The geographic position and the diversity of geological, pedological, hydrological, relief, and climate factors are some of the reasons for a high biodiversity in Kosovo (KAS 2019). But also the (still) existing near-natural forests in large parts of the mountains of Kosovo and the partly extensive agriculture, especially in the cultivation of grassland, are important for the country's biodiversity. Compared to its relatively small area, Kosovo is rich in plant species. To date, approximately 1,800 vascular plant species have been confirmed, and botanical experts believe that the actual number is closer to 2,500. About 150 to 200 plant species that grow in Kosovo are found only in the Balkans (Balkan endemics) and 13 are found only in Kosovo (Kosovo endemics) (USAID 2003).

Kosovo is situated in the sub-Mediterranean floristic region that is known for its rich flora, especially in near-natural habitats (cf. e.g., Fritsch 1909, 1918, Rexhepi 1976, Millaku 1999, Stevanović et al. 2003). Kosovo's plant diversity is the result of the complex interaction of physical factors such as soil type, elevation and microclimate and land-use practices creating a wide variety of habitat conditions for plant growth. Kosovo's plant diversity is further enriched by the presence of species driven south during ice age periods in Northern and Central Europe. All this has contributed to the fact that Kosovo, along with neighboring countries, is an important hotspot of European biodiversity (Myers et al. 2000). Particularly the Sharr/Sara Mountains in the south and the Bjeshket e Nemuna/Prokletije Mountains in the west are well known for high biodiversity (USAID 2003). The former is protected as a national park and the latter is proposed for national park status. Moreover, the Pashtriku/Pastrik limestone landscape in the northwestern part of the country that is influenced by Mediterranean climate and the mountains of Koritniku/Koritnik in the southwestern part of Kosovo support over 40 Balkan and Kosovo endemic plant species. However, neither of these areas is currently protected (USAID 2003). This is problematic against the background that the biodiversity of natural and near-natural ecosystems in Kosovo is endangered in many places (USAID 2003, Mustafa 2004): Since the turn of the century, particularly since the 1960s, remaining forest areas have been severely degraded due to firewood harvesting, grazing, and agricultural clearing. Although forests cover approximately 40% of Kosovo, only about a third of this area is considered ecologically healthy and productive for forestry production. Several species in natural and near-natural habitats are known to be on the verge of extinction in Kosovo or are already locally extinct, owing largely to human actions, such as illegal clearing of forests and intensive collection of species used by Kosovo's and neighboring countries' pharmaceutical industries.

In addition to the biodiversity of natural and semi-natural habitats, the biodiversity of agricultural land is also important for overall biodiversity. This applies to 'agrobiodiversity', i.e.

'the variety and variability of animals, plants and micro-organisms at the genetic, species and ecosystem levels that sustain the ecosystem structures, functions and processes in and around production systems, and that provide food and non-food agricultural products' (FAO 1999), but also to the diversity of many 'wild' animal and plant species in agricultural landscapes, i.e. to the 'associated biodiversity' and their communities.

As in many other regions of the world, agrobiodiversity is also endangered in Kosovo: Autochthonous breeds such as white goats are hardly used in today's agriculture, as more productive breeds were imported, and old varieties of cereals and fruits are also hardly cultivated anymore due to their low productivity. The 'Sharri herding dog' has a special value, because it is an autochthonous dog breed for Kosovo and more attention should be paid to it (MESP n.d.).

With regard to the natural, near-natural and associated biodiversity in Kosovo, studies were carried out several decades ago, especially on the vegetation, which proved a high diversity at that time. For example, Rexhepi (1976) identified 139 plant associations in Kosovo, including 68 forest plant associations, 38 found in alpine and subalpine zones, 28 found in hill and mountain meadows, five in lowland meadows, one in wetlands, and one in running water. Further studies were conducted by Kojić and Pejčinović (1982), also published by Pejčinović (1987) and Pejčinović and Kojić (1988), and Shala (1987). According to these publications, the vegetation of the arable land was species-rich and differentiated to environmental factors and agricultural management. In the recent past, several studies on the diversity of weeds in arable fields of Kosovo and on the effects of herbicide use were conducted (Susuri et al. 2001, Mehmeti 2003, 2004, 2009, Mehmeti et. al. 2009, Mehmeti et al. 2010, Mehmeti et. al. 2012). These studies show that today's weed vegetation is fairly species-poor at the plot scale and dominated by a few highly competitive weeds causing yield depression.

While the associated biodiversity in arable land is obviously endangered by increasing intensification of arable farming, there is partly an opposite development in grassland: Since the war in 1998/99, grazing of alpine pastures has decreased because, until today, farmers and shepherds have been afraid in remote border areas. As grazing has been reduced, some pastures have fallen fallow and have become subject to the process of successive reforestation, and this may lead to the loss of rare upland grassland species. In the lowlands, grassland biodiversity is also at risk for at least two reasons: In the last two decades, grasslands have been partially plowed and are now used to grow crops. Another problem is the increasing illegal construction of buildings on former grasslands.

To date no study has focused on the vineyards of Kosovo, and thus profound information on the recent species composition of weed communities in vineyards and their relations to land use (e.g. weed management practices) and environmental conditions (e.g. soil fertility) is not available at all.

2.1.4 Agricultural land use and societal frame of Kosovo

In Kosovo, the agricultural sector is still of the greatest economic importance, but was severely affected by the war in 1998/99: A high proportion of livestock was killed and agricultural machinery was also destroyed. Since then, however, numerous efforts have been made to strengthen the agricultural sector (Miftari 2017). This is particularly important in light of the fact that two-thirds of Kosovo's population lives in rural areas and is directly dependent on agricultural production. The land used by large state-owned enterprises in the Yugoslavian era has been privatized for the most part in recent decades. As a result, most farms today are very small, averaging less than 2 hectares divided into smaller land parcels, which makes efficient cultivation of agricultural land with machinery difficult and contributes to the fact that yields are still very low, e.g. 3 tons of corn per ha, and are far from sufficient to feed the livestock and population (Mehmeti 2009, MAFRD 2013, Miftari 2017).

According to KAS (2019), in Kosovo the used area of agricultural land (including common land) is 420,141 hectares (Table. 2). The largest part of the agricultural land belongs to meadows and pastures (including common land) with 51.9% and arable land with 44.8%. Other land-use categories such as plantations, gardens and seedlings cover less than 10% of the area. The arable land is mainly used for crop production (mainly wheat and corn) (65.9%) and cultivation of forage plants (19.9%). Vegetables, potatoes, legumes, industrial plants and several other cultivated plants are grown on a total of about 15% of the agricultural land. Crop production is concentrated in the central plains and two major valleys, mixed cereal production and vineyards are typical of the central and peripheral hilly areas, and pattern of grassland and forest ecosystems predominate in the mountainous regions.

Table 2: Agricultural land use in Kosovo

Land-use category	Area (ha)
Meadows and pastures (including common land)	217,932
Arable land	188,365
· from which vegetables in the open field (first crop)	8,319
· from which vegetables in greenhouses (first crop)	518
Plantations of fruits	9,244
Plantations of vineyards	3,367
Garden	1,122
Seedlings	111
Total used area of agricultural land	**420,141**

Data Source: Kosovo Agency of Statistics (2019)

Although the wine industry only accounts for a small part of Kosovo's agricultural sector, it holds the great potential for access to European and overseas markets, in which the demand for imported wines is high. Before 1999, the annual production was up to 12.5 million €, with a processing capacity of 30,000 - 40,000 tons of grapes and 10 million liters of wine per year. 80% of the products were exported to European markets, USA and Canada. In 2001 an agreement was reached with a German company for the export of 200,000 liters of wine for the next 5 years, starting from 2002, and in the following years the international wine trade was rapidly expanded. In 2004 about 2.4 million kg of red and white wine grapes were harvested for wine as well as for the table, of which 1.1 million liters of white and red wine (Cabernet Sauvignon, Merlot, Pinot Noire, Game, Kosovo Red, Chardonnay, Italian Riesling, Rhine Riesling, Semignon) and other spirits like grape brandy were produced. Since then, the international wine market has been further expanded. Due to government subsidy policies and various international grants, the demands of farmers are increasing for the cultivation of grapevine crops (Data GISconsulting 2020).

2.2 The study regions: Location, climate, soils and wine production

2.2.1 Geographic location, topography, water network and population of the study regions

The municipality of **Rahovec** (study region Rahovec) is located in the western part of Kosovo. To the north, it borders with the municipalities of Klina and Malisheva, to the south with the municipality of Mamusha, and about 16 km to the east with the municipality of Suhareka, the second study region of this research. The distance to Prishtina, the capital of Kosovo, is about 60 km in direction northeast. The municipality is well connected by the highway and an old railroad line between the cities Prizren and Peja. The territory of Rahovec has an area of 275.5 km², lies partly in the central and southern part of the Dukagjini plain and is divided into three parts with different topography characterized by a plain-valley, hills, and mountainous. The hydrographic network of the municipality of Rahovec consists of several hundred springs, wells, current and stable springs, as well as streams. The main rivers in the municipality of Rahovec are Drini i Bardhë river, the Hoca river, the Bellaja river, and the Rimnik river (GISconsulting 2013).

Settlements in the municipality of Rahovec are located at altitudes between 310 m a.s.l. (Krusha e Madhe) up to 920 m a.s.l (Zatriqi) (Data GISconsulting 2013). In the municipality of Rahovec live about 56,208 inhabitants (KAS 2013), distributed in a total of 36 settlements, including Rahovec city, with on average 204 inhabitants per km². About 40% of the total population are younger than 20 years, whereas only 6% are older than 65. With regard to ethnic affiliation, the municipality of Rahovec has a very homogeneous population where over 98% are Albanians (KAS 2013)

The municipality of **Suhareka** (study region Suhareka) is located east of the municipality of Rahovec and west of the municipality of Ferizaj. To the north the municipalities Malisheva, Lipjan and Shtime border, and to the south the municipalities of Prizren, Mamusha and Shërtrpce. The average altitude in the municipality is 455 m a.s.l and several mountains are located in the northwest, east and south of Suhareca city. The surface of the municipality is 361.8 km², of which the majority (53.7%) is used for agricultural production. Forest cover about 41.7% of the municipality's area (Data GISconsulting 2013). The municipality of Suhareka has a developed hydrographic network with a large number of rivers that pass through the territory of the municipality. However, during dry weather in most of the rivers, there is little or no water at all, and during the rainy season, there are often local floods. The largest river in the municipality is the Toplluha river.

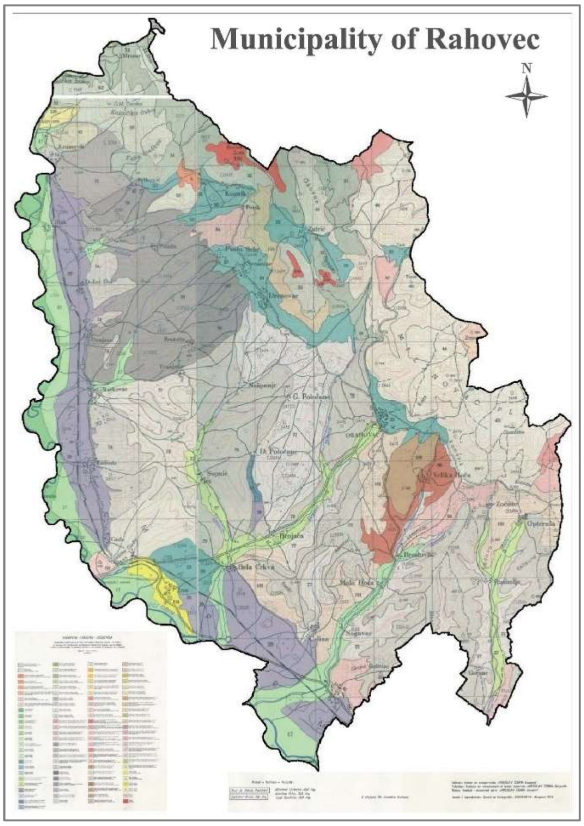
According to KAS (2017) the municipality of Suhareka has 41 settlements, where 88,126 inhabitants live with a population density of 165 inhabitants per km². The age structure of the population is similar to that in the municipality of Rahovec and like there the Albanian population dominates with 98.9% in the municipality of Suhareka.

2.2.2 Climate and soils of the study regions

The most important factors that affect the climate of the study region **Rahovec** are a small distance to the Adriatic Sea (about 100 km to the estuary of the river Drini i Bardhe in the Adriatic Sea) and a considerable range in altitudes from about 308 m a.s.l. in the Drini i Bardhë river valley at Krusha e Madhe and up to 1,039 m a.s.l. at the top of Zatriq, which means an average of 550 m a.s.l. in the entire area of the municipality. The climate is continental with a pronounced Mediterranean influence (GISconsulting 2013). In the municipality of Rahovec, the average annual temperature is 11.7 °C. The average rainfall is 708 mm. Snowy days in Rahovec, mainly in January, are on average 15.7. The continental climate in the municipality of **Suhareka** has a less pronounced Mediterranean influence. The average annual air temperature (11.0 °C) and the annual rainfall (674 mm) are a bit lower than in the Rahovec region (Data GISconsulting 2020).

In both regions, there is a wide range of different soils, which are base-poor to calcareous, loamy to clayey and shallow to deep. According to a recent work of the Institute of Geodesy at University of Prishtina (Ameti and Ajvazi 2021), calcareous soils (calcaric cambisols, calcaric luvisols, calcaric vertisols, calcaric haplic vertisols, calcaric luvic vertisols, calcic cambisols, calcaric regosols) are present on about 100 km² of the municipality of **Rahovec**. Incidentally, for both areas there is only one comprehensive soil survey from Pavićević (1974). By this author, the most frequent soil types in the municipality of **Rahovec** are various types of smonitza (noncalcareous, brownized or eroded), i.e. soils that according to the WRB-soil classification (IUSS WorkingGroup WRB 2015) ae named as Vertisols that have a clay content of at least 30%.

The cultivation of these soils, which dry out considerably in summer and are subject to cracking, is very problematic. They are therefore more suitable for permanent crops than for arable farming. Furthermore, various loamy soils are present in the Rahovec region (Figure 1). In the region of **Suhareka**, a pattern of brown soils on schist, loamy pseudogleys, smonitza (brownized or eroded), and several other loamy to clay soils are developed (Figure 2).



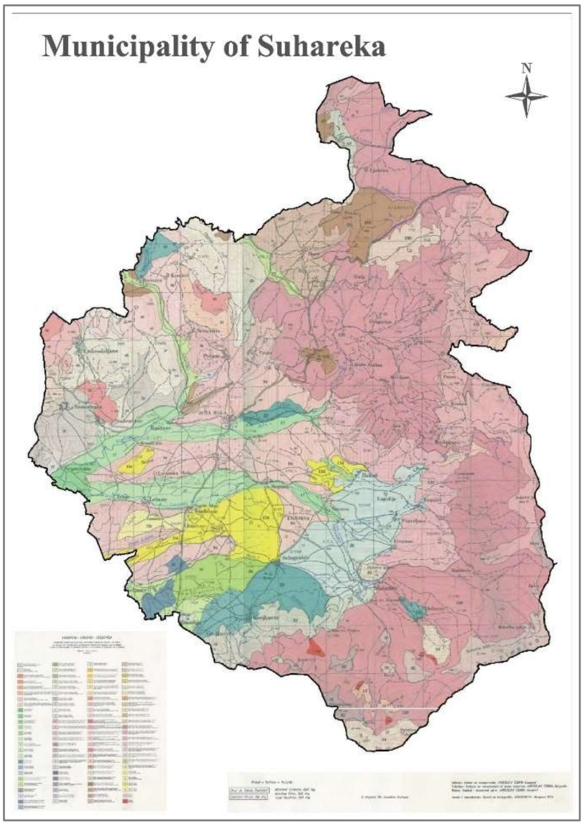


Figure 1 and 2: Diversity of soils in the municipalities of Rahovec and Suhareka
(taken from Pavićević 1974)

2.2.3 Wine production in the study regions

The municipality of **Rahovec** with its rich history in wine production and fertile land has great potential for future developments. Economic development in the municipality is oriented mostly in viticulture, but the cultivation of crops and vegetables is important too. The total area of vineyards (Figure 3) in the municipality is 2168 ha, with a trend of increasing the area. The vineyards are located in the hilly part of the municipality, where deep loamy, calcareous soils are particularly favorable for viticulture and the quality of the wine. Besides smaller wineries, there is one large winery in the municipality of Rahovec, where meanwhile 13 million liters of red and white wines are produced per year and mainly exported to European countries, the USA and African countries. An increasing number of small regional wine producers deliver to this company. The production standards of the large vinery are high and the cultivation of the land is predominantly intensive (Figure 4). However, since 2021, about 80 hectares have also been farmed organically and the wine produced accordingly is certified as organic in the EU. The company uses the infrastructure of a state-owned winery, which during the time of socialist Yugoslavia exported large quantities of low quality wines under the name "Amselfelder", especially to Germany, and has significantly expanded this former company and improved the quality of the wine produced (StoneCastle 2022).

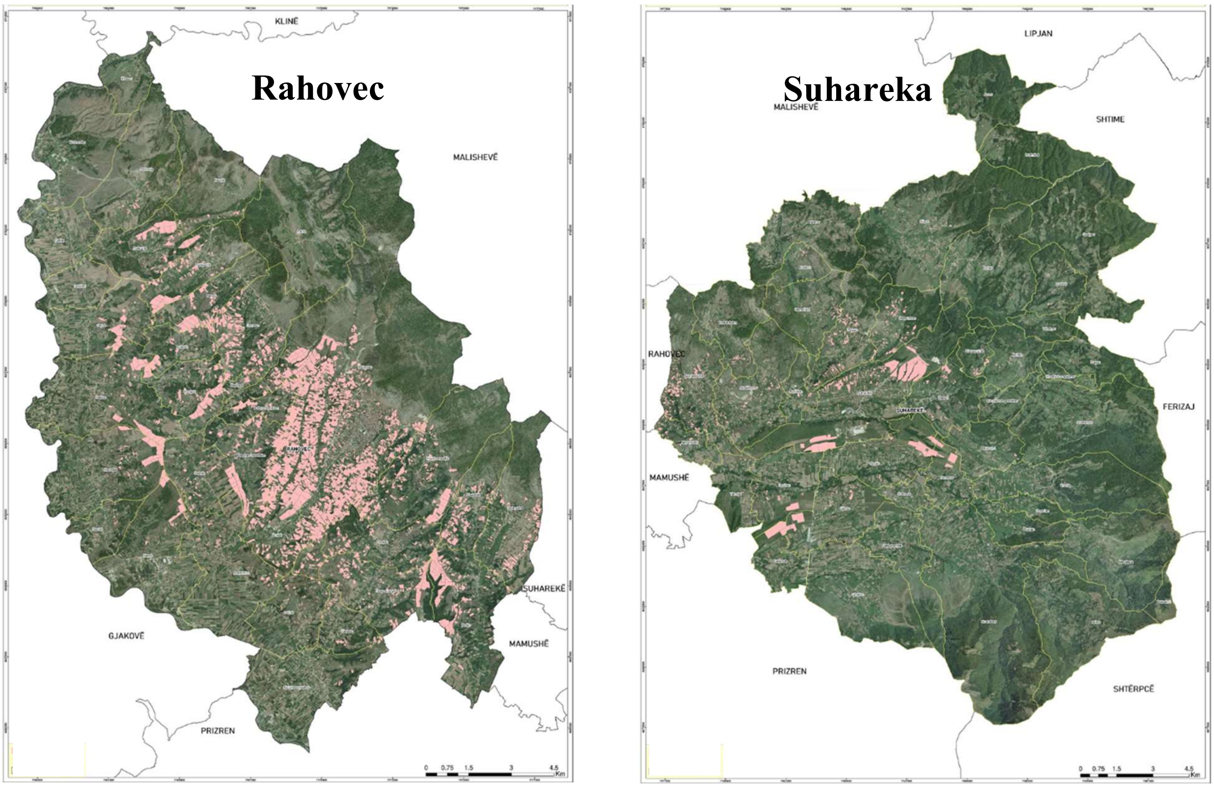


Figure 3 and 5: Vineyard plantations in the municipalities of Rahovec and Suhareka
(provided by Geo&Land, Kosovo; vineyards in pink color)

Also the municipality of **Suhareka** is known for the cultivation of grapevines and the production of grapes and wine. According to data from the "Department of Viticulture and Enology", 514 ha vineyards (Figure 4) were used for production in 2018, respectively 256 ha for wine grapes and 258 ha table grapes, belonging to the private sector and planted in 2589 separate plots. This wine-growing area is thus significantly smaller than the one of the municipality of Rahovec and the individual vineyards are also often smaller. As in the Rahovec region, mainly hilly parts of the municipality are used for the production of grapes and wine. Some of the vineyards are characterized by higher weed infestation, indicating less intensive cultivation (Figure 6).

Figure 4 and 6: Weed vegetation in vineyards of Rahovec region and Suhareka region, Kosovo, 2016

3. Literature review

3.1 Arable weed vegetation including vineyards and weed management

The weed vegetation on agricultural land is a potentially diverse and highly dynamic component of Central European biodiversity (Holzner 1978, Holzner and Immonen 1982, Ellenberg 1996), and many studies about decreasing flora and vegetation of vineyards are at hand (e.g. for Switzerland: Arn et al. 1997a, b; for Germany: Wilmanns 1989, 1999; for Hungary: Pál 2004). It is well known from these studies that intensive growing technologies (e.g., high mulching intensity, frequent soil disturbance, use of herbicides), but also invasive and herbicide-resistant weeds have negatively affected the native weed flora and vegetation of vineyards.

From a phytosociological point of view, the vegetation of the vineyards, i.e. the plant association *Geranio-Allietum vinealis Tx. 1950* belongs to the subclass *Violenea arvensis* Hüppe & Hofm. 1990, i.e. to the arable weed vegetation (Hüppe and Hofmeister 1990). Before 1990, the phytosociological classification of the arable weed vegetation was according Braun-Blanquet et al. (1936) and Tüxen (1950). All these phytosociological classifications initially apply to the former and recent situation in Germany and neighboring countries, but can also be applied to Kosovo for the following reasons: The arable vegetation in Kosovo is subject to basically the same antropogenic disturbances (including tillage for sowing crops in autumn or spring, fertilization, mechanical or chemical weed control) and is common on base-poor to calcareous and on dry to moderately moist sites. Also, as described by Hüppe and Hofmeister (1990), the vegetation of the vineyards is found on sunny slopes of different parent material such as shell limestone, schist, clay layers and loess, whereas today's weed vegetation is depleted in many places. The latter applies to all plant associations of the *Violenea arvensis* and is due to various processes such as frequent herbicide application, intensive fertilization, enhanced seed treatments, simplified crop rotations and abandonment of marginal sites (Sieben and Otte 1992, Albrecht 1995, Matson et al. 1997, Gerowitt 2003, Fried et al. 2008, Simmering et al. 2013). Consequently a strong change in the composition of weed species has taken place in arable vegetation in the last century (Sutcliffe and Kay 2000, Marshall et al. 2003, Mehmeti 2009, Hawes et al. 2010). Although weeds are known to adapt to changes in 'natural' site conditions and management practices (Kojić and Šinžar 1996), not all of the weed species succeed (Hofmeister and Garve 2006). The reason is that for many weeds the ecological niche of occurrence is very small in relation to natural site conditions and their changes (e.g. through fertilization) (Ellenberg et al. 1992).

Seed germination is the first step in the plant life cycle, and the timing of seed germination and germination rates have major implications for biological invasions (Schlaepfer et al. 2010). Germination strategies are critical for species and vegetation establishment in changing landscapes and for the continued spread of species, especially for annual native and invasive species such as ragweed (Leiblein-Wild et al. 2014). Reproduction by seeds is characteristic to almost all vascular plants. It is widely acknowledged that seed size is negatively related to seed production by a fundamental trade-off (Shipley and Dion 1992, Jakobsson and Eriksson 2000). The production of high numbers of small seeds is typical for many weed species and enhances dispersal efficiency (Tackenberg et al. 2003, Poschlod et al. 2005, Bruun and Poschlod 2006). In general, seeds may germinate shortly after maturation and dispersal or after a more or less long period of seed dormancy in the soil (Benech-Arnold et al. 2000, Jimenez-Lopez 2020) depending of the species-specific longevity in soils (Thompson et al. 1993, Thompson 2000, Grime 2001).

The species-specific germination strategies and their response to environmental factors like temperature and water supply during the first stage of their life cycle can be characterized by the variables ‘germination time’, ‘synchrony’ and ‘total germination’ (Baskin and Baskin 2001, Ranal and de Santana 2006). Air temperature plays a crucial role in many biological and physiological processes in plants (Al-Ahmadi and Kafi 2007, Berti and Johnson 2008), and the effects of temperature on the seed germination process and the vulnerability of plan seedlings are highlighted in numerous studies (e.g., Otte 1996, Gunter 1997, Akhalkatsi and Losch 2001, Otte et al. 2006). However, also light and substrate affect seed germination in a species dependent manner and may promote or inhibit the germination process (Carvalho and Nakagawa 2000).

Among the anthropogenic disturbances in agriculture, tillage directly affects weed germination and emergence by loosening the soil, which favors seed germination, and also by altering the seed distribution in the soil (Colbach et al. 2005, Gaba et al. 2007). In addition, weed seeds are usually exposed to short periods of light in conjunction with soil disturbances. Annual weeds, which are predominantly so-called light germinators (Ellenberg 1996), can use this short exposure to light as a germination stimulus to detect the optimal time for germination in the respective habitat (Milberg et al. 2000).

The main reason why weed vegetation differs in different regions, even with comparable management, soils and cultivation intensity, is the climate, which varies widely within Europe. Significant differences in weed species composition were found to be associated with a complex gradient of increasing altitude and precipitation and decreasing temperatures in Central Europe (Lososová et al. 2004), and climatic factors were shown to determine the weed species composition both in the Czech Republic and Hungary (Lososová and Cimalová 2009, Pinke et al. 2009, 2010, 2011, 2012). Numerical methods, such as cluster and correlation analyses, and multivariate techniques such as canonical correspondence analysis, are useful tools to better understand the relationships between weed diversity, natural site conditions and management practices (e.g., Streibig 1979, Salonen 1993, Kenkel et al. 2002). This is further required in order to establish sustainable weed management on local scales that integrates the requirements of nature and environmental protection as well as those of agriculture (Gary et al. 2009, Mariana and Vastola 2015, Gilinsky et al. 2016).

As already outlined in the introductional chapter, weeds have many beneficial effects on the agroecosystem and many weeds are endangered today, because they are considered a problem from the agronomic point of view. Worldwide, there are about 8000 weeds and many of them cause damage and reduce crop productivity in different ways (Holm et al. 1979). Thus, weed control, either mechanical or chemical, is a very important management measure of growing grapevines. Currently, grape growers can choose between three major techniques of weed management: Tillage, non-tillage or chemical control via the use of herbicides and the sowing of a weed suppressing plant cover (temporary or permanent). Also, there are many different manual, mechanical and chemical weed control methods available (Goldammer 2018). The effectiveness of the different weed control techniques in vineyards depends largely on the flora present, so it is necessary to make an inventory of the plants in order to select the most suitable method for a given vineyard. Thus, several studies were conducted on the effectiveness of different soil management measures on the weed species composition of vineyards in different regions (Guillerm et al. 1990, Ticchiani et al. 19991, Lososova et al. 2003, Delabays et al. 2005). Several problems are associated with tillage and the use of herbicides as weed control measures, such as erosion, the contamination of groundwater, and the appearance of resistance. Consequently, changes in weed management have been discussed and partly implemented (Moreira 1994, Monteiro and Moreira 2004), and integrated weed management has gained importance as a solution approach (Scienza and Miravalle 1987, Travlos et al. 2018).

3.2 Soil management in vineyard ecosystems

Soil is a natural resource that plays a key role in terrestrial ecosystems. For example, soil organic matter (SOM) is an essential component of soils as it supports soil structure, fertility and a range of physical properties that positively affect water availability to plants (Fang et al. 2005, Zhao et al. 2005). Consequently, a decrease of SOM can lead to drastic impairment of the soil physical and chemical properties, with negative impacts on soil nutrient cycling mechanisms (Bauer and Black 1994, Loveland 2003). In the light of the climate change debate, SOM is furthermore discussed as an important storage pool for carbon (Batjes 1992, Horwath and Kuzyakov 2018, Navarro-Pedreño et al. 2021).

Soil management in vineyards is of great importance for production (Wheeler et al. 2003, 2005, Pickering and Wheeler 2006, Jacometti et al. 2007, Guerra et al. 2012). Soil conservation and improvement of soil nutrients, along with other management measures in viticulture such as weed and pest control, have positive effects on vine vigor, vine growth, and wine quality (Afonso et al. 2003, Thomson and Hoffmann 2007, Nazrala 2008, Sharley et al. 2008, Trivellone et al. 2012). Poor soil management can damage soil structure, which in turn adversely affects soil nutrient availability, water holding capacity, infiltration, and biological activity (Dilley 2007, Glover et al. 2000, Merwin et al. 1994, Stamatiadis et al. 1996). Soil management methods have an effect on photosynthesis and stomatal conductance of the vines (Marangoni et al.2001, Judit et al. 2011), and also the nutrient uptake of the grapes is affected by soil compaction, soil moisture and the warming of soils, which partly depends on the before mentioned soil properties. For example, a positive correlation between soil temperature and the uptake of nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg) exists (Bogoni et al. 1995).

4. Material and methods

4.1.1 Vegetation and site data

In May to August 2016 and 2017, the weed vegetation was documented on a total number of 70 randomly selected vineyard patches (35 patches in Rahovec and 35 patches in Suhareka). On each of the 70 patches, four plots were selected randomly for detailed vegetation sampling. Each plots was divided into two subplots 'within rows' and 'between rows' with a standard size of 1 m x 5 m (Figure 7). To avoid edge effects, the minimum distance of each subplot to the patch border was 5 m. For each subplot, the composition of the vascular plant species was documented based on a modified Braun-Blanquet scale (Barkmann et al. 1964) as shown in Table 3. Unknown species were determined by using atlases (e.g., Saric 1991, Mehmeti et al. 2015). Additionally the total weed cover (% of covered soil) and the mean height of the weed vegetation (cm) was estimated. About half of the fieldwork was conducted in the first year (2016). In the second year (2017), the fieldwork was completed.

Moreover, the proportional affiliation of the recorded species to life forms according to Raunkiaer (Ellenberg and Müller-Dombois 1967), mono- versus dicotyledons and plant families were calculated based on information from available datasets (e.g., Ellenberg et al. 1992, BfN 2022).

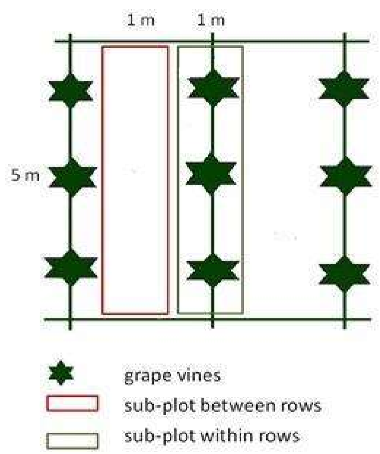


Figure 7. Sampling design with subplots within and between rows of grape vines.

Table 3. Species cover (abundance/dominance) as recorded in the field and transformed to values of 'mean percentage species cover' as considered in the quantitative analyses

A	r	+	1	2a	2m	2b	3	4	5
A (%)	0.1	1.0	2.5	10	15	20	37.5	62.5	87.5

A: Species cover (abundance/dominance) as recorded in the field
Scale according to Barkman et al. 1964.
A (%): Mean percentage species cover as considered in data analysis.

The location of each patch (Figure 8 and 9) and plot was recorded with the help of a GPS using the UTM system. For each plot, additional site data were documented in the field or derived from maps: height in m above sea level; exposition, aspect, 'northness' (cosine of aspect), and 'eastness' (sine of aspect). Based on interviews with the farmers, who managed the patches, further information was compiled for each patch on herbicide use (Rahovec: 15 patches without and 20 patches with herbicides; Suhareka: 29 patches without and 6 patches with herbicides).

Soil sampling (soil depth: 5-15 cm) in the respective subplots within and between rows was conducted using a hand auger. In each subplot, the soil of three subsamples was mixed. About half of the soil sampling was conducted in the first year (2016); in the second year (2017), the soil sampling was completed. Each of the mixed soil samples were dried at room temperature, sieved (to exclude stones >2 mm from further soil analysis), and stored at room temperature until analysis in the same years. Soil pH was measured in both $H_2O_{dest.}$ and 0.01M $CaCl_2$ (DIN ISO 10390 2005). The total amount of organic matter (OM) was determined by the ignition method (Schlichting et al. 1995). The amount of plant-available P and K was quantified with the help of the Calcium-Acetate-Lactate extraction method (CAL; Schüller 1969).

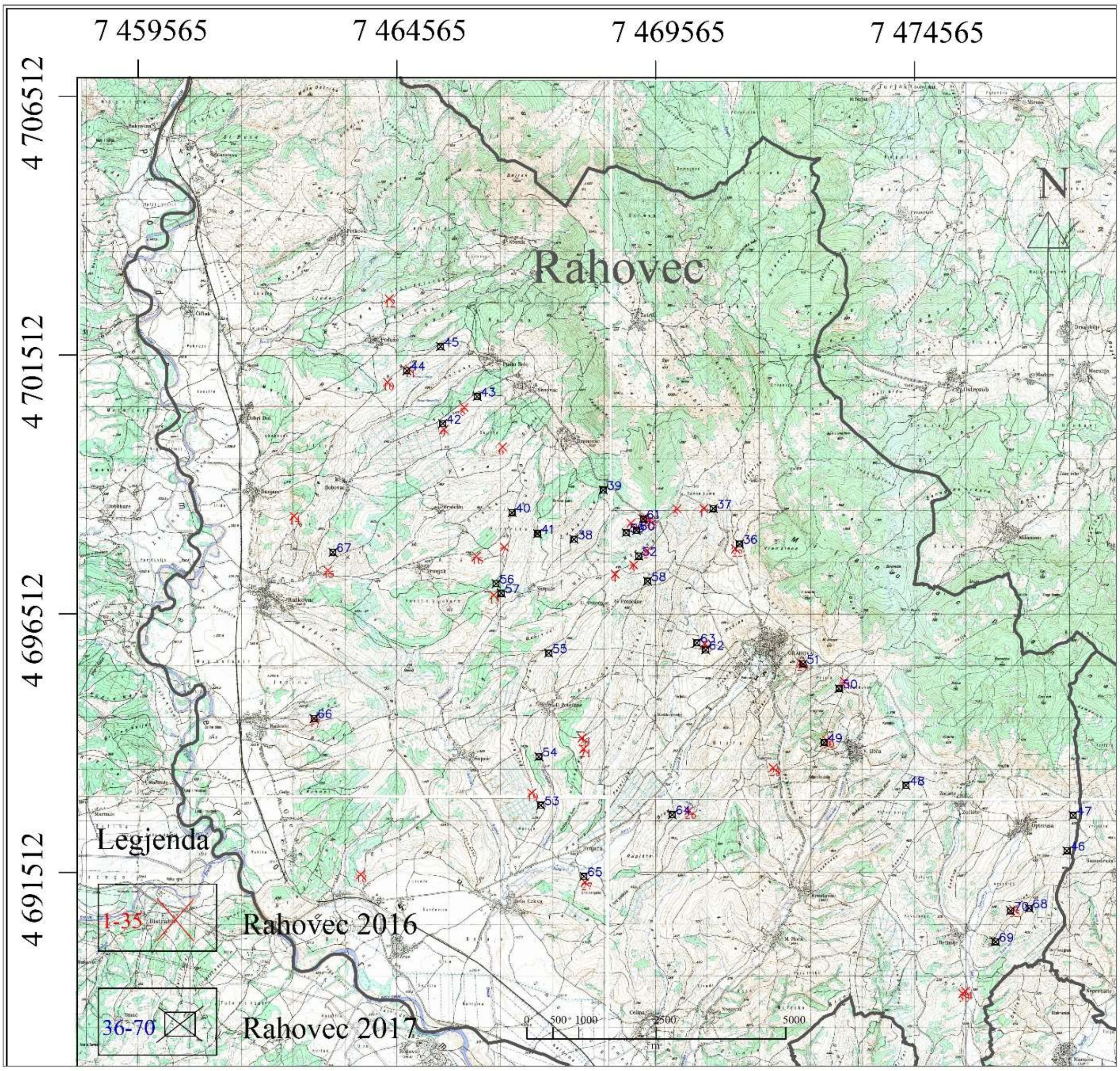


Figure 8: The location of the studied vineyard patches in Rahovec

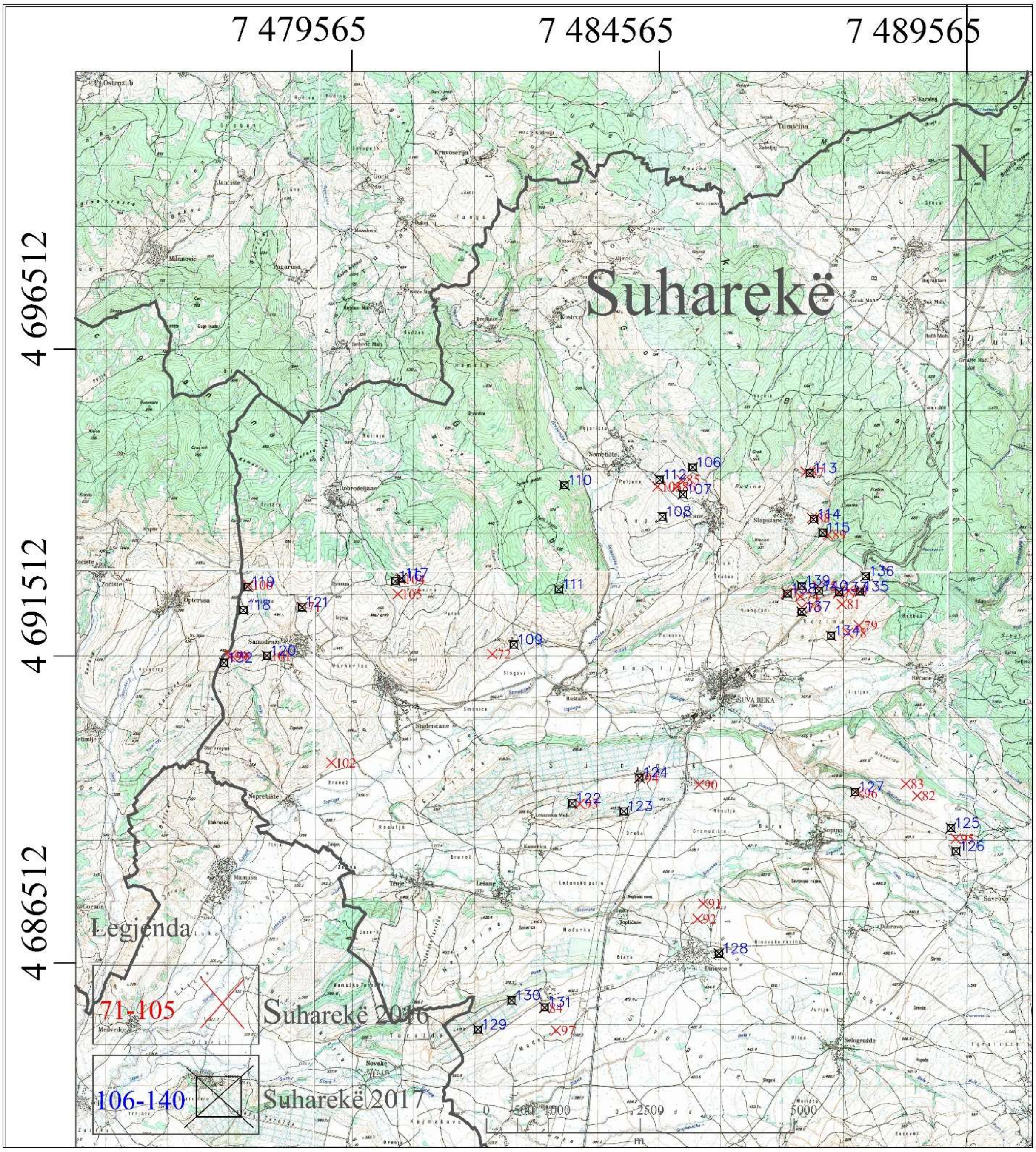


Figure 9: The location of the studied vineyard patches in Suhareka

4.1.2 Germination experiment in climate chambers

For four selected weed species relations between air temperature and germination was analyzed in a climate chamber experiment. The experiment was conducted in climate chambers at Justus-Liebig University Giessen. As described in Otte (1996) and Hölzel and Otte (2004), the germination succeed was tested for different temperatures ranging from 3 °C to 30 °C. Five replicates with a standard number of 50 seeds per species and temperature level were analyzed. The germination experiment lasted for about 12 weeks in winter 2017/18.

Mature seeds of the four species were sampled on the patches of both study regions that were investigated in the first year of the project, respectively, in 2016. The germination experiment was conducted with seeds of the F1-generation of the sampled seeds. Additionally, a tetrazolium test was conducted to quantify the viability of the seeds of the F1-generation. 15 seeds of each species per region were tested and more than 90 % of all tested seeds were viable.

4.1.3 Germination experiment under field conditions

In addition to the climate chamber experiment, relations between air temperature and seed germination of the F1-generation of the four selected species mentioned above were analyzed under field conditions in 2018 on the experimental field of the Agricultural Faculty of University Prishtina next to the city. In standardized plots (30 cm x 30 cm) with heat-sterilized soil (to prevent germination of seeds that may occur in the soil) a standardized number of 200 seeds per species were investigated by means of weekly recordings within the entire vegetation period, i.e. from early March to late October. In these recordings the number of germinated was documented. For each of the selected species, three replicates were investigated to allow statistical analysis of the data. To relate these data to the air temperature during the vegetation period the minimal and maximal air temperature next to the plots was recorded daily with the help of a temperature data logger that was protected from sun light.

4.1.4 Data analysis and statistics

Analysis of vegetation and site data

Data analysis and statistics aimed to compare the weed vegetation between the two study regions and between distinguished management types, and to relate the vegetation data to the considered soil and management data. Thus, the data were analyzed with methods such as Detrended Correspondence Analysis (DCA), multivariate analysis or ANOVA (Leyer and Wesche 2008).

DCA analysis was used due to rather long gradients in compositional turnover encountered within the data set. In the DCA analysis rare species were not downweighted and the species dataset was ln-transformed to meet missing normal distribution of the vegetation data. Quantitative vegetation and site data (weed cover, species height, species number, 'northness', 'eastness' and the soil chemical data) were considered in the analysis and were passively projected on an ordination scatter plot (joint biplot; cutoff r^2 value: 0.10). Analyses were conducted with the help of the PC-software PC-ORD Vers. 5 (McCune and Mefford 1999, McCune and Grace 2002).

The same PC-ORD software was used for Indicator Species Analysis (Dufrêne and Legendre 1997) to derive significant indicator species for the considered qualitative categories year (2016, 2017), region (Rahovec, Suhareka), location of subplots ('within rows', 'between rows'), and herbidide use (yes, no).

Analysis of germination experiments

Regarding the four selected species, the aim was to compare their germination behavior among each other and between the two regions. In the climate chamber experiment, weighted average germination rates reached at the end of the 12-week experiment were calculated and compared, and In the field experiment, the average germination rates of the three replicates for each species at the end of the vegetation period.

The analysis of the climate chamber experiment was conducted according to Otte (1996) and Hölzel and Otte (2004). LOPT, the optimal temperature for germination, was calculated as weighted average of the germination rates over all constant temperatures and according to the equation:

$$(3\,P3 + 10\,P10 + 20\,P20 + 30\,P30)/\,(P3 + P10 + P20 + P30)$$

where P3 was the percentage germination at 3°C, P10 the percentage germination at 10°C, P20 the percentage germination at 20°C, P30 the percentage germination at 30°C; LOW, the lowest constant temperature with a germination rate of at least 5%; HIGH, the highest constant temperature with a germination rate of at least 5%; AMP, the range in degrees Celsius between HIGH and LOW.

Further, the data of the climate chamber experiment as well as the field experiment were tested with pairwise T-tests and multifactorial Anova. Analyses were conducted with the help of the PC-software STATISTICA 6.0 (Anon. 1998) and the open software RStudio (RStudio Team 2020).

5. Results

5.1 Weed flora, vegetation and relations to site conditions

Overall 84 weed species were recorded in the sampled subplots of the municipalities of Rahovec and Suhareka in 2016 and 2017. The total species list, differentiated by years, study region and location of the subplots 'within' or 'between rows' is compiled in Table A1 (Annex). In the first year, 71 species were recorded, of which 60 were found in the Rahovec and 59 in the Suhareka region. In the second year, 73 weed species were found in both regions, of which 56 were sampled in the Rahovec and 67 in the Suhareka region. In both regions and in both years, the number of species was considerably higher in the subplots 'within the rows' than in those 'between the rows'.

Species belonging to 28 families were collected (Table A2; Annex). The family *Asteraceae* was found to be the largest in vineyards of Rahovec and Suhareka region, with 17% of all recorded species, followed by *Poaceae* with 12% and *Fabaceae* with 11%. Most of the recorded species are dicotyledons (86%), whereas the number of monocotyledons (14%) is much smaller. Regarding life forms, the majority of the species in the two vineyard regions are therophytes, and most of the perennial species are hemicryptophytes (Figure 10).

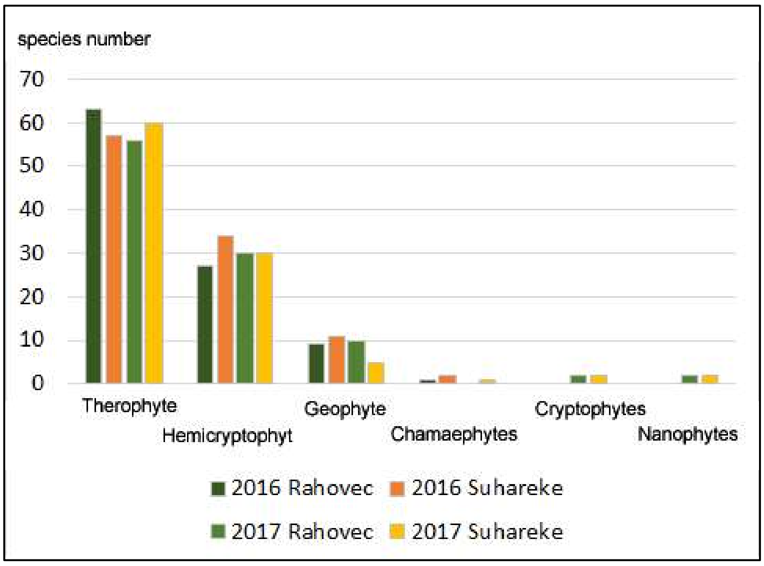


Figure 10: Life forms in vineyards of Rahovec and Suhareka region in 2016 and 2017
Plant life forms as given in Ellenberg et al. (1992)

Table 4 gives an overview on the results of the soil chemical analysis. The data for each subplot are electronically stored at the Chair of Landscape Ecology and Landscape Planning of Justus Liebig University Giessen. The mean values of the organic matter were higher in the Suhareka region than in the Rahovec region and also higher 'within rows' compared to 'between rows', whereby this applies to both regions. Further, the mean pH_{H2O} values are higher 'within rows' compared to 'between rows' in both regions.

Table 4: Soil chemical data of the studied vineyards in the municipality of Rahovec and Suhareka

Soil depth: 5-15 cm; year of soil sampling: 2016; $p < 0.05$.

Plot location	Soil parameter	Mean	Min.	Max.	Std.Dev.
Rahovec					
- Within rows	OM (%)	4.9 [a]	1.0	12.1	1.8
n=140	P_2O_5 (mg/100g)	12.5	<0.1	117.3	14.7
	K_2O (mg/100g)	28.5	2.3	88.4	13.1
	pH H_2O	6.2 [a]	4.4	8.9	5.4
	pH $CaCl_2$	5.7	4.1	8.3	5.0
- Between rows					
n=140	OM (%)	4.5 [b]	<0.1	8.3	2.1
	P_2O_5 (mg/100g)	18.7	<0.1	219.1	35.4
	K_2O (mg/100g)	27.9	3.8	82.3	12.3
	pH H_2O	5.8 [b]	4.2	9.0	5.1
	pH $CaCl_2$	5.6	4.0	8.3	4.9
Suhareka					
- Within rows	OM (%)	5.3 [c]	1.9	9.5	1.6
n=140	P_2O_5 (mg/100g)	11.4	0.4	70.1	13.5
	K_2O (mg/100g)	31.6	4.7	93.2	17.0
	pH H_2O	6.1 [a]	4.6	8.9	5.6
	pH $CaCl_2$	5.6	4.2	8.3	5.0
- Between rows					
n=140	OM (%)	4.9 [a]	0.9	13.7	1.8
	P_2O_5 (mg/100g)	11.9	<0.1	69.5	12.3
	K_2O (mg/100g)	31.4	7.6	177.1	21.6
	pH H_2O	5.8 [b]	4.4	9.0	5.3
	pH $CaCl_2$	5.5	4.2	8.3	5.1

In the overall dataset (n=560) of the vegetation relevés (electronically stored at the Chair of Landscape Ecology and Landscape Planning of Justus Liebig University Giessen), the most frequent species (rf=percentage frequency) are the common weeds *Convolvulus arvensis* (rf=72.1%), *Echinochloa crus-galli* (rf=70%), *Chenopodium album* (rf=52.9%), *Xanthium* *strumarium* (rf=44.6%), *Amaranthus retroflexus* (rf=29.0), *Lactuca serriola* (rf=26.6), *Cirsium arvensis* (rf=25.9), *Elymus repens* (rf=25.4) and *Stellaria media* (rf=19.5). In contrast, *Consolida regalis, Plantago lanceolata, Achillea millefolium, Lamium amplexicaule, Mentha arvensis, Chenopodium ficifolium, Equisetum arvense, Fumaria officinalis, Lathyrus aphaca, Trifolium aerum* and *Veronica agrestis* were found in less than 1% of the relevés.

Table 5 gives an overview on the species numbers in the subplots with a standard size of 5 m² recorded in 2016 and 2017. Seven out of the total number of 560 subplots were not considered here and in the DCA ordination analyses, because the vegetation of these subplots sampled in the Rahovec region in 2016 were obvious outliers according to the DCA. The mean values of the species numbers do not differ significantly between years and regions, but were higher within rows and lower in herbicide-treated subplots.

Table 5: Species numbers of the studied vineyard subplots in the municipality of Rahovec and Suhareka
n = number of subplots; size of subplots: 5 m x 1 m; * p< 0.001

Species number	**2016**	**2017**	**Rahovec**	**Suhareka**	**within rows**	**between rows**	**herbicide**	**no herbicide**
n	*273*	*280*	*273*	*280*	*276*	*277*	*216*	*337*
Mean	6.8	6.0	5.7	7.0	7.9 [a]	4.9 [b]	5.0 [a]	7.3 [b]
Min.	1	2	1	2	2	1	1	2
Max.	13	14	12	14	14	12	13	14
Std.Dev.	2.70	22.64	2.62	2.63	2.49	1.93	5.00	2.53

A DCA was conducted for 553 subplots of the 560 sampled (7 outliers) subplots in 2016 and 2017. The total inertia is 9.600 and the gradient lengths along the first to third axes are 4.613, 3.887 and 3.586. 42 % of the total variance in the dataset is explained by the first three axes of the n-dimensional space. The joint plot of the DCA (Figure 11) indicates differences in weed cover, vegetation height and species numbers along the first DCA axis, between the two years with slightly higher values in 2016.

Another DCA was compiled with the data (n=253) from the first year of the study. The total inertia is 7.263 and the gradient lengths along the first to third axes are 3.500, 3.322 and 2.806. 30 % of the total variance in the dataset is explained by the first three axes. According to the joint plot of this DCA (Figure 12), the vegetation slightly differs between the locations of the subplots 'within' and 'between rows' with higher species numbers and vegetation height within rows.

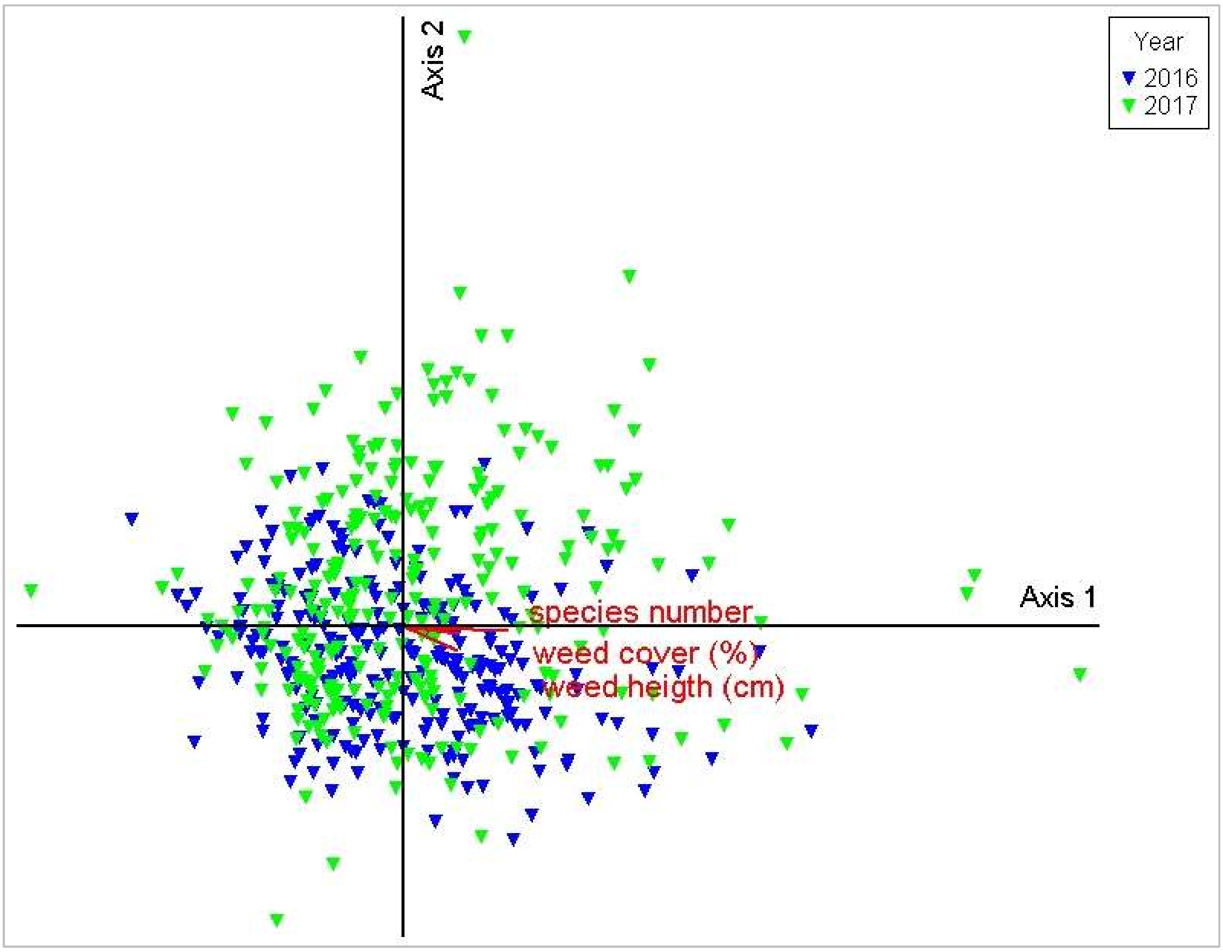


Figure 11: Detrended correspondence analysis (DCA) diagram of the vineyard vegetation in both study regions in 2016 and 2017

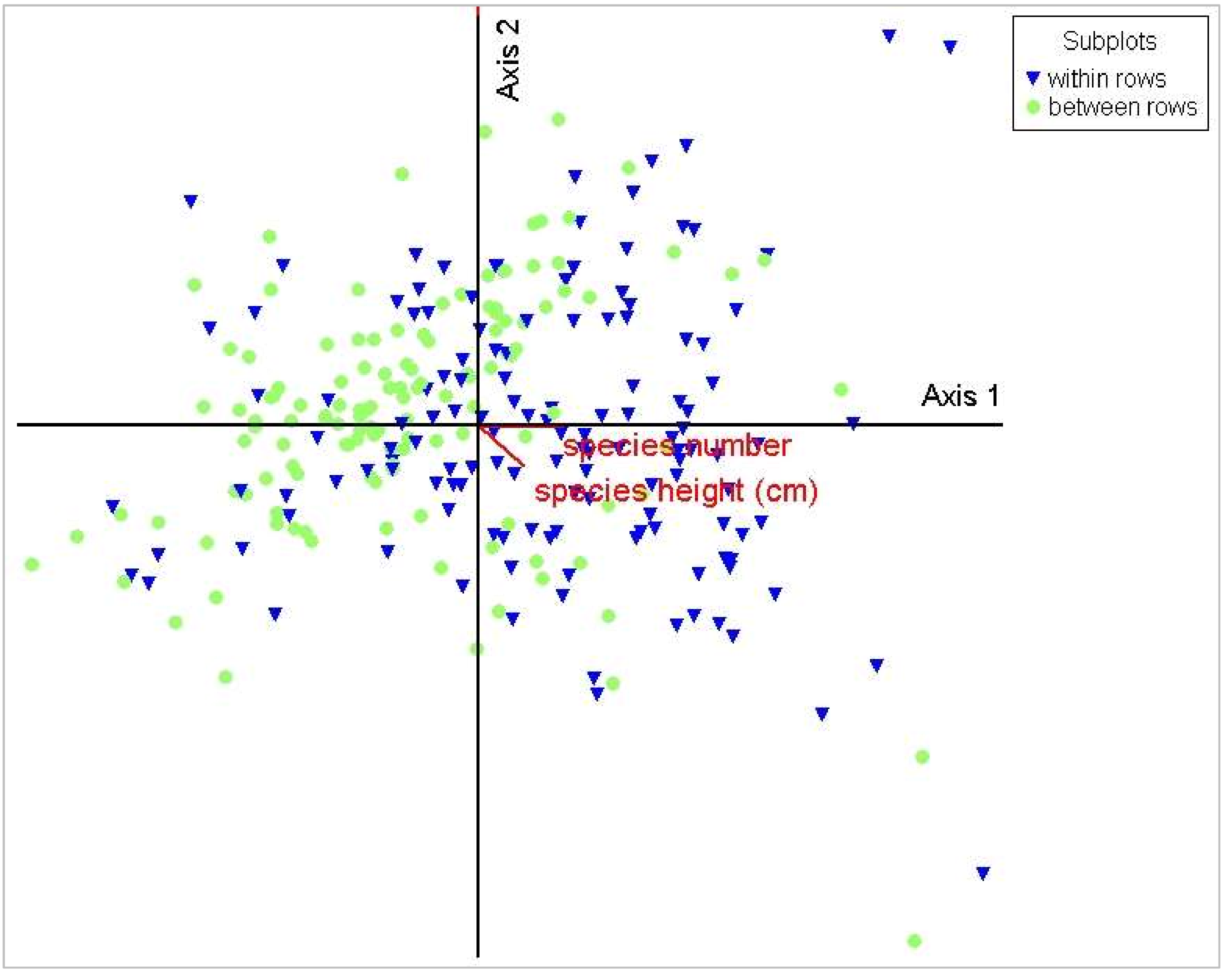


Figure 12: Detrended correspondence analysis (DCA) diagram of the vineyard vegetation in both study regions within and between rows in 2016

According to the **Indicator Species Analysis** conducted for the data from 2106 and 2017 (n=553) only two species were indicating the yeas: *Echinochloa crus-galli* (indicator value = 51,9; p=0.0002) indicates 2016, whereas *Elymus repens* (indicator value=37.3; p=0,0002) was more frequent and/or reched higher abundances in 2017. Focusing on the dataset from 2016, several species are indicaters of the study regions, location of the subsamples and herbicide use (Table 6). However, the region Rahovec, the ‘location between rows’ and the management practise ‘with herbicide use’ are nocht characterized by indicator species.

Table 6: Indicator species in vineyards of Kosovo in 2016
Number of subplots: 273; only species with indicator values > 20 are considered

Species	Indicator value	p value
Indicators for Suhareka region		
Cirsium arvense	24.4	0.0102
Convolvulus arvensis	48.6	0.0004
Xanthium strumarium	28.2	0.0476
Indicators for 'within rows'		
Lactuca serriola	36.9	0.0002
Senecio vulgaris	24.3	0.0002
Stellaria media	39.4	0.0002
Indicators for 'without herbicide use'		
Amaranthus retroflexus	23.5	0.0438
Cirsium arvense	28.3	0.0022
Chenopodium album	42.3	0.0006
Convolvulus arvensis	47.8	0.0040
Echinochloa crus-galli	49.6	0.0426
Xanthium strumarium	34.6	0.0012

5.2 Germination behavior in the climate chambers experiment

Germination responses to different temperature regimes in the climate chamber experiment are presented in Table 7. For weed species originating from the Rahovec region, the optimal temperature of germination in the climate chamber experiment is higher than for those from the Suhareka region. The optimal temperature of germination of *Amaranthus retroflexus* and *Solanum nigrum* in Rahovec region is 30°C. Lowest constant temperatures with a germination rate of at least 5% and highest constant temperature with a germination rate of at least 5% were higher for the species *Amaranthus retroflexus, Echinochloa crus-galli* and *Chenopodium album* originating from Suhareka region. The range in degrees Celsius between HIGH and LOW (AMP) was higher for seeds originating from the Rahovec region.

Table 7: Seed germination characteristics of *Amaranthus retroflexus, Echinochloa crus-galli, Chenopodium album* and *Solanum nigrum*

Regions: S = Suhareka, R = Rahovec; C = Climate chamber experiment, F =field experiment

In accordance with Olff et al. (1994): LOPT = optimal temperature for germination, LOW = lowest constant temperature with a germination rate of at least 5%, HIGH = highest constant temperature with a germination rate of at least 5%, AMP = range in degrees Celsius between HIGH and LOW.

Region	LOPT		HIGH		LOW		AMP	
	C	F	C	F	C	F	C	F
Amaranthus retroflexus								
S	28	22	30	20	20	/	10	20
R	30	26	30	/	/	/	30	/
Echinochloa crus-galli								
S	21	23	20	20	10	/	10	20
R	/	25	/	/	/	/	/	/
Chenopodium album								
S	20	25	30	/	20	/	10	/
R	21	25	20	/	3	/	17	/
Solanum nigrum								
S	29	26	/	25	/	/	/	25
R	30	26	30	/	/	/	30	/

The results of the climate chamber experiment with temperatures ranging from 3 °C to 30 °C are presented in Figure 13. The number of germinated seeds is highly different between species and temperatures.

According to multifactorial testing, the germination rates of *Echinochloa crus-galli, Chenopodium album* and *Solanum nigrum* collected in the Suhareka region were higher than those collected in the Rahovec region. Moreover, there is a significant difference between regions at the different temperatures regarding germination of *Amaranthus retroflexus* and *Chenopodium album* (P *0.00040).

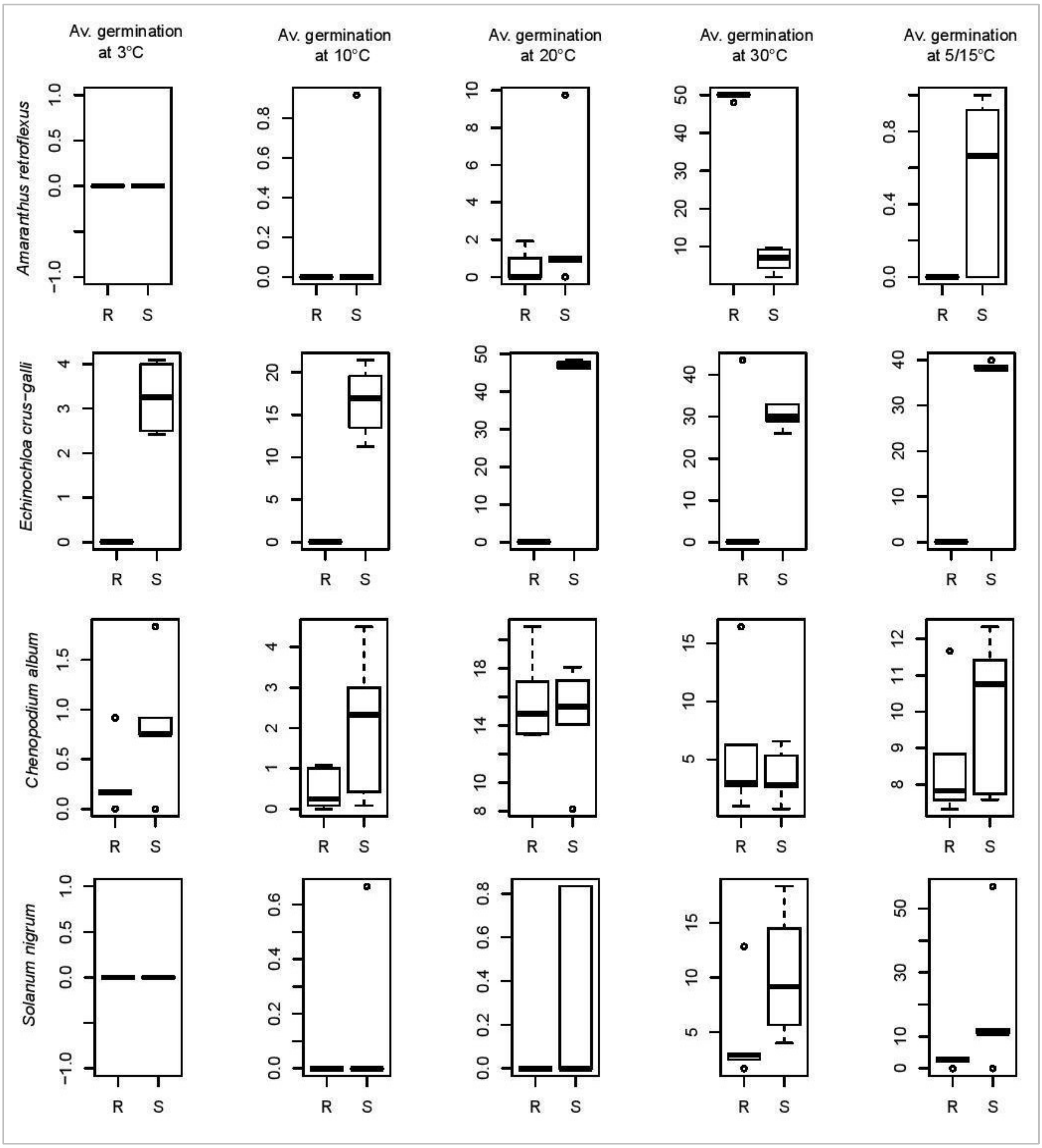


Figure 13: Seed germination of *Amaranthus retroflexus, Echinochloa crus-galli, Chenopodium album* and *Solanum nigrum* in the climate chamber experiment
Values show the means and standard errors for five replicates with a standard number of 50 seeds per species and temperature level; R – Rahovec region; S – Suhareka region

5.3 Germination behavior in the field experiment

In the vegetation period 2018, the air temperature was measured daily next to the plots of the experiment under field conditions at the experimental site of the Agricultural Faculty of Prishtina. The lowest air temperature was reached in March, the highest in August. The values for each day are electronically stored at the Chair of Landscape Ecology and Landscape Planning of Justus Liebig University Giessen. Under field conditions, for all species from both regions the optimal temperature is 22-26 °C (see Table 7).

Germination started in the first week of the experiment for three species in both regions, except for *Amaranthus retroflexus* seeds collected in the Rahovec region and for *Chenopodium album* seeds collected in the Suhareka region. By the end of experiment, 96% of *Chenopodium album*, 65% of *Solanum nigrum*, 22% of *Amaranthus retroflexus* and 10% of *Echinochloa crus-galli* seeds from the Rahovec region had germinated, and 94% of *Echinochloa crus-galli,* 90% of *Solanum nigrum,* 66% of *Amaranthus retroflexus* and 31% of *Chenopodium album* seeds from the Suhareka region. Results obtained in the seed germination experiment under field conditions are presented in Figure 14 for temperatures between 20 to 30 °C. Results show a significant interaction of temperature and species of Suhareka region, respectively at temperatures 20°C and 25 °C for *Chenopodium album* (P *0.00349), 20°C and 30 °C for *Amaranthus retroflexus* (P *0.00232).

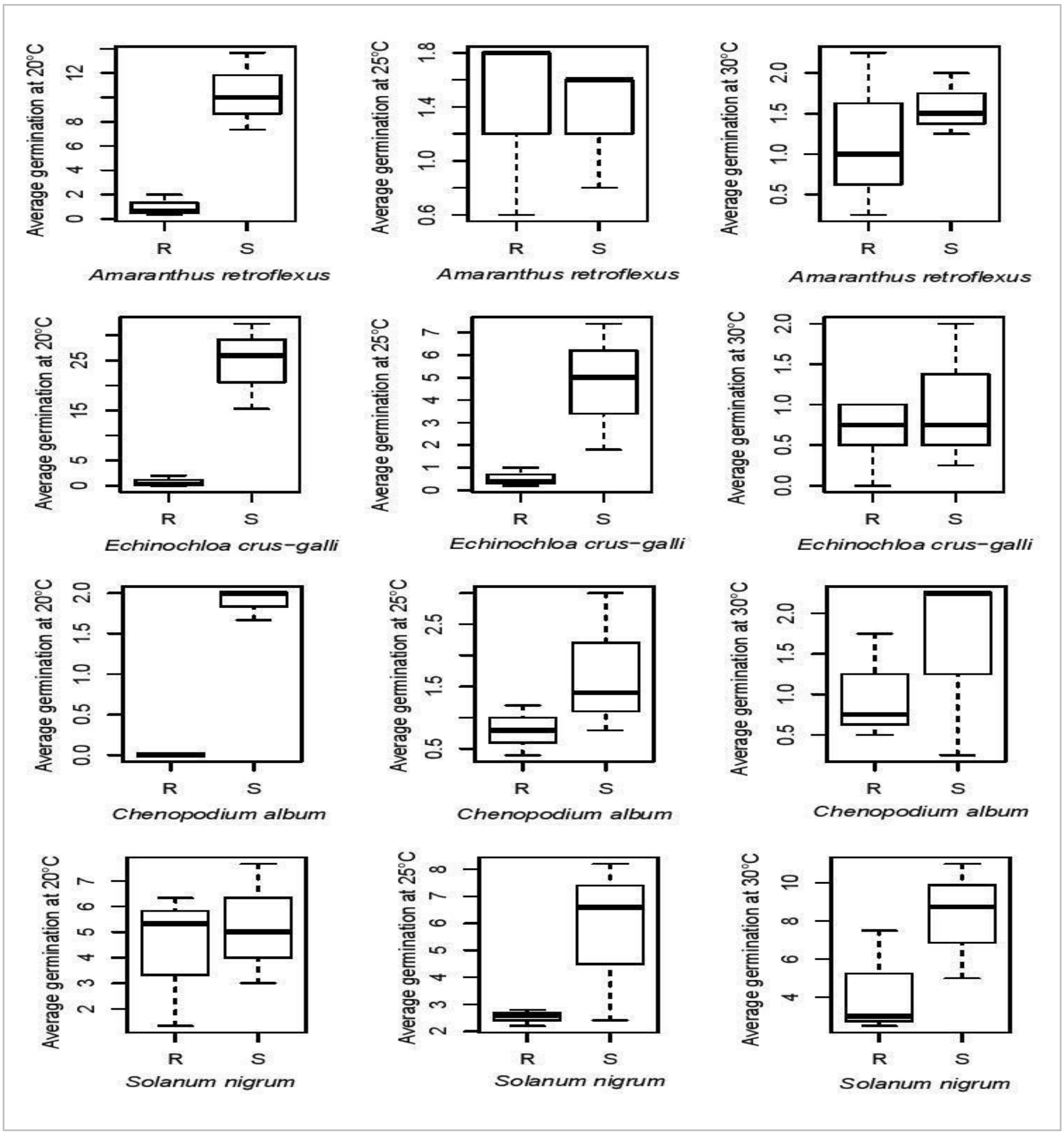


Figure 14: Seed germination of *Amaranthus retroflexus, Echinochloa crus-galli, Chenopodium album* and *Solanum nigrum* in the field experiment

Only germination at temperatures between 20 to 30 °C is shown. Values show the means and standard errors for three replicates with a standard number of 200 seeds per species; R – Rahovec region; S – Suhareka region

6. Discussion

6.1 Diversity of the weed vegetation and its drivers in vineyards of Kosovo

In the vineyards of the municipalities of Rahovec and Suhrareka surveyed in 2016 and 2017, a total of only 84 weed species was found, with only about six species developed in the mean of all vegetation survey plots with a standard area of 5 m². As in many other wine-growing regionss in Europe (see chapter 3), the predominantly intensive use with herbicide applications and frequent soil disturbances of the vineyards in Kosovo is not suitable for the development of species-rich vegetation. Mechanical weed control, which is practiced by most farmers in early spring, and also the use of total herbicides 'between the rows', counteract the formation of species-rich arable weed vegetation (Fetahaj et al. 2017). Only very rarely species-rich vineyard vegetation can be found even today on a small scale in the Rahovec region. Kabashi et al. (2020) describe a vineyard patch with 21 species that included rare species such as *Bifora radians*. However, such patches are apparently so rare that they are almost impossible to detect when study plots are randomly selected, as was done in the present work.

Several decades ago, similar species-poor vineyards as in the present study were found in other wine-growing regions in the area of former Yugoslavia: In a study on the impact of hoeing in vineyards on weed flora in vineyards of the Medvednica region in present-day Croatia, Hulima (1979) detected a total of 89 plant species. Also in present-day Croatia, Plavšič-Gojkovič et al. (1986) in the Jastrebarsko region and Vrbek (2000) in the Žumberak region found only 72 resp. 66 plant species and explained this by herbicide use and hoeing 'between the rows'. In contrast, according to Kovačević et al. (2015), a total of 133 vascular plant species developed in vineyards of Bosnia and Herzegovina. However, it is not possible to evaluate whether this is due to lower land-use intensity there.

In general, the species richness of arable weed vegetation in Europe, which includes vineyard vegetation, has declined sharply since about 1970 due to intensification of cultivation methods (Storkey et al. 2012). This loss of floristic diversity also has negative consequences for the faunal diversity. For example, Ragasová et al. (2021) found a close positive correlation between the number of invertebrates and both the abundance and number of vineyard weeds in the Czech Republic.

The vegetation recorded in the present study is predominantly composed of dicotyledonous species from a total of 28 plant families. Although the number of species is low, this means a wide range of different species groups, which are important for the fauna of the agricultural landscape, plant-pollinator interactions and pest regulation (Tscharntke and Brandl 2004, Bianchi et al. 2006). However, the vineyards of the Rahovec and Suhareka regions have only a few geophytic species and among them none of the species of the genera *Allium* and *Muscari* typical for vineyards, which can also be expected in vineyards of Kosovo. On the other hand, annual arable weeds such as *Echinochloa crus-galli, Chenopodium album* and *Amaranthus retroflexus* occur with high relative frequencies and high abundances. These annual weeds are in general common in arable vegetation, including those in vineyards, due to spring tillage, fertilization and partly as a result of herbicide resistance, and are among the most problematic weeds in agriculture worldwide (e.g., Holm et al. 1991, Ghorbani et al. 1999, Guo and Al-Khatib 2003, Sellers et al. 2003, Costea et al. 2004, Steckel et al. 2004, Thomas et al. 2006, Chauhan and Johnson 2009, Tanveer et al. 2009, Feng and Youyong 2010).

The flora of the vineyards of both regions Rahovec and Suhareka does not differ much from each other. With *Cirsium arvense, Convolvulus arvensis* and *Xanthium strumarium*, only three species are indicator species of the Suhareka region, i.e. are found there more frequently and/or with higher abundances. A somewhat lower land-use intensity in the Suhareka region, but also a somewhat higher age of the stands studied there, which could explain the higher OM contents of the soils 'within the rows' in the Suhareka region, could be causes for this. Stronger differences in the species composition are also not to be expected due to the spatial proximity of both study regions. Also when comparing the two study years, the overall floristic composition is quite similar, as expected, although according to the DCA results, the small-scale species composition differed somewhat between the two study years, possibly due to differences in the weather conditions.

However, there are more distinct differences in the species richness of the subplots 'within' and 'between the rows': The significantly higher overall species numbers 'within the rows' in both regions in both years are due to lower soil disturbance and lower herbicide applications there to keep the risk of damage to the vines low. The small-scale higher species numbers 'within the rows' in the vegetation surveys, which are typical for both regions, can also be explained in this way. In addition, *Lactuca serriola* and *Senecio vulgaris*, two perennial ruderal species, are indicator species of the vegetation 'within the rows' and this also indicates a lower soil disturbance there. In contrast, the use of herbicides 'between the rows' has a strong effect on the vegetation. *Amaranthus retroflexus, Cirsium arvense* and four other widespread weeds develop significantly more frequently and/or with higher abundances as indicator species in the patches not treated with herbicides, demonstrating the positive effect of this form of weed management from an agricultural perspective.

The question is whether the current cultivation methods in the two study regions Rahovec and Suhareka can cope with climate change and other challenges facing viticulture. Today, a substantial body of literature is available on the effects of climate change with increasing summer drought, but also extreme weather events with heavy rainfall in viticulture and wine production, including effects on vine physiology, phenology, grape composition, and wine quality (e.g., Mira de Orduna 2010, Fraga et al. 2012, Mosedale et al. 2016). In this context, several authors also describe potential impacts on pests and diseases (Caffarra et al. 2012, Bois et al. 2017). In light of this, inter-row management has been changed in many viticultural areas in recent decades by specifically greening the soil instead of hoeing it and keeping it open as in the past. This benefits the water balance of the soils and also biodiversity (e.g. Purgar and Hulina 2004, Celette et al. 2008, Fiera et al. 2020). The great importance of cover plants and adapted weed management for these and other ecosystem services in viticulture was studied by Guerra et al. (2022) in a long-term project in Mediterranean vineyards. In this study, it was also demonstrated that noxious weeds were more abundant in herbicide-sprayed rows compared to greened vineyards. However, it was also shown that the yields of the greened patches were lower.

In the Rahovec region, harvesting machines were used for the first time in 2022 (Figure 15). The background of this development is the need to harvest the ripe grapes within a few weeks to ensure the quality of the harvest. In both study regions, Rahovec and Suhareka, this is increasingly hampered by a lack of harvest workers. Here, a fundamental societal problem in Kosovo with increasing emigration of young people is leading to a worrying change in viticulture, which could have a negative impact on soil quality in the longer term. It can be assumed that the use of machines will lead to soil compaction with effects on e.g. water storage capacity and soil biodiversity. It is known, not least from an extensive review article, that soil management and soil quality in wine-growing areas are crucial for numerous ecosystem services and also for the quality of the wine (Giffard et al. 2022).

Figure 15: Mechanical grape harvest in Rahovec region in September 2022

However, not only the management on the cultivated patches is important for biodiversity in vineyards. In a study of 78 vineyards (patch level) and their landscape context - landscape sections with a radius of 750 m around the vegetation surveyed were examined - in Austria, France, Spain and Romania, Hall et al. (2020) demonstrated that the diversity of the surrounding landscape structure (pattern level) has a positive effect on the diversity of vineyard vegetation on the patch level. This is in agreement with numerous landscape ecology studies on the diversity of flora and fauna in agroecosystems (e.g., Burel et al. 1998, Duelli and Obrist 1998, Dauber et al. 2003, Thies et al. 2003).

6.2 Germination behaviour of selected vineyard weed species and potential reasons for species-specific differences

As expected, the climate chamber and field experiments with four selected weeds from both study regions show species-specific differences in germination behavior, with all studied species as so-called summer annuals (Ellenberg et al. 1992) germinating best at temperatures above 20 degrees. In addition, the studied populations of the same species differed between the two regions, which was not expected due to the close proximity of the regions and basically similar management of their vineyards. It is particularly interesting that the seeds of the populations from the Rahovec region germinated well over a wider range of temperatures and that the germination rates of *Echinochloa crus-galli, Chenopodium album*, and *Solanum nigrum* from the Suhareka region were significantly higher than those of the same species from the Rahovec region.

The regional differences found in the germination behavior of the studied species could be due to the fact that the weeds are exposed to the influence of herbicides to different degrees. In Rahovec, herbicides, including glyphosate in particular, are used in most vineyards, while in Suhareka herbicide use is less frequent. In general, herbicide use leads to the development of herbicide resistance (Prado et al. 1997, Beckie 2020) and even small amounts of herbicide can rapidly lead to herbicide-tolerant variants (Manalil et al. 2011). This may have led to genetic differences in the weeds studied, as herbicide effects on seed production and also on germination behavior of arable weed species have been demonstrated in several studies (Rotches-Ribalta et al. 2015, Boutin et al.2014, Andersson 1996, Biniak and Aldrich 1986, Carrithers et al. 2004).

For the winegrowers of the Rahovec and Suhareka regions, the results can be helpful for a more targeted weed management. The use of contact herbicides against the weeds studied should only be applied in the spring when temperature-dependent germination has actually occurred. Alternatively, pre-emergence herbicides could be applied earlier in the spring (Goldammer 2018). However, the use of herbicides is always associated with the problems that herbicide-resistant variants of weeds may emerge. Mechanical weed management does not pose this risk. Also, as described in chapter 6.1, weed management could be more sustainable through organic production and greening 'between the rows'.

7. Conclusions

The vineyard vegetation of both study regions Rahovec and Suhareka is species-poor on patch level with about 5 to 7 species per 5 m². The land-use intensity with herbicide applications and frequent soil disturbance on the majority of the studied patches does not allow the development of species-rich vegetation.

This is basically also true for the patches 'in the rows', where the intensity of disturbance is lower and the species diversity is higher by about 2 species per 5 m² than 'between the rows'.

The predominantly high intensity of disturbance is indicated by the predominance of therophytes in the vegetation. Geophytes of the genera *Allium* and *Muscari*, formerly typical of vineyard vegetation, cannot develop under these conditions in the managed vineyards.

The diversity of soils in both study areas is not reflected in the vegetation. Widespread weed species predominate, such as *Echinochloa crus-galli*, *Chenopodium album* and *Amaranthus retroflexus* which are considered agricultural problem species in cropland and vineyards.

Species richness is also low on pattern level, with a total of only 84 species in the 560 studied plots in both 2016 and 2017. Vegetation diversity is slightly higher in the Suhareka region than in the Rahovec region apparently due to the lower intensity of farming there.

Significant differences in temperature-dependent germination behavior of *Echinochloa crus-galli, Chenopodium album* and *Solanum nigrum* given in the comparison of the two study regions, indicate genetic differences in the populations, which may be a consequence of different levels of herbicide use in the regions. Further studies, including on the degree of herbicide resistance of weeds, are needed in this regard.

A greater proportion of organically managed vineyards would be important for more species-rich vineyard vegetation on patch and pattern levels. Pesticide use should be avoided and 'between the rows' greening should be allowed. However, this form of cultivation has no history in either region, and it remains to be seen whether a trend change has been initiated with the first steps in this direction, which have been taken in the Rahovec region since 2021.

The soil management practiced in both study regions, which aims to minimize plant cover, should be questioned more thoroughly. Targeted greening and no hoeing of the soils have been shown to be beneficial for many ecosystem services in many grape-growing regions, although this reduces harvest volumes.

The use of machines for grape harvesting, which has been evident in the Rahovec region since 2022, is understandable in view of the lack of workers and the need for fast harvesting, but should be viewed critically, not least in terms of soil protection. Soil ecology studies should be carried out for this purpose.

8. References

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Erklärung gemäß der Promotionsordnung des Fachbereichs 09 vom 7. Juli 2004 § 17 (2)

„Ich erkläre: Ich habe die vorgelegte Dissertation selbständig und ohne unerlaubte fremde Hilfe und nur mit den Hilfen angefertigt, die ich in der Dissertation angegeben habe. Alle Textstellen, die wörtlich oder sinngemäß aus veröffentlichten Schriften entnommen sind, und alle Angaben, die auf mündlichen Auskünften beruhen, sind als solche kenntlich gemacht. Bei den von mir durchgeführten und in der Dissertation erwähnten Untersuchungen habe ich die Grundsätze guter wissenschaftlicher Praxis, wie sie in der „Satzung der Justus-Liebig-Universität Gießen zur Sicherung guter wissenschaftlicher Praxis“ niedergelegt sind, eingehalten”.

Annex

Table A1: Total species list recorded in vineyards of Kosovo in 2016 and 2017 and abbreviations of species names.

W – within rows; B – between rows; Abbr. – abbreviation of species names (see Figures 11 and 12)

No.	Weed species	2016				2017				Abbr.
		Rahovec		Suharekë		Rahovec		Suharekë		
		W	B	W	B	W	B	W	B	
	Number of species	84								
		71				74				
		60		59		56		67		
		57	33	57	48	51	38	64	45	
1	*Achillea millefolium* L.			*	*					Ach.mill.
2	*Alopecurus mysourides* Huds.	*	*	*		*	*	*		Alo.myos.
3	*Amaranthus Blitoides* L.	*	*			*		*	*	Ama.blit.
4	*Amaranthus retroflexus* L.	*	*	*	*	*	*	*	*	Ama.ret.
5	*Anagallis arvensis* L.		*	*	*	*		*	*	Anag.arv.
6	*Anthemis arvensis* L.			*	*			*	*	Anth.arv.
7	*Aristolochia clematitis* L.	*	*	*	*	*	*	*	*	Aris.cle.
8	*Artemisia vulgaris* L.	*		*	*			*		Art.vul.
9	*Avena fatua* L.	*		*		*	*	*		Ave.fat.
10	*Bifora radians* M. Bieb.	*		*	*	*		*	*	Bif.rad.
11	*Bromus sterilis* L.	*		*	*	*	*	*		Bro.ste.
12	*Capsella bursa pastoris* L.	*	*	*	*	*	*	*	*	Cap.burs.
13	*Centaurea cyanus* L.	*		*	*			*		Cen.cyan.
14	*Chenopodium album* L.	*	*	*	*	*	*	*	*	Chen.alb.
15	*Chenopodium ficifolium* Sm.							*		Chen.fici.
16	*Cichorium intybus* L.							*	*	Cich.inty.
17	*Cirsium arvense* (L.) Scop.	*	*	*	*	*	*	*	*	Cir.arv.
18	*Consolida regalis* S.F (Gray)						*	*		Con.reg.
19	*Convolvulus arvensis* L.	*	*	*	*	*	*	*	*	Con.arv.
20	*Conyza candensis* (L.) Cronq	*		*	*	*	*	*	*	Con.cana.
21	*Cynodon dactylon* L.			*	*					Cyn.dact.
22	*Dactylis glomerata* L.	*	*			*	*	*	*	Dac.glom.
23	*Datura stramonium* L.		*	*		*	*	*		Dat.stra.
24	*Daucus carota* L.	*	*	*	*	*	*	*	*	Dau.carr.
25	*Echinochloa crus-galli* L.	*	*	*	*	*	*	*	*	Ech.c.galli.
26	*Elymus repens* (L.) P.Beauv.	*	*	*	*	*	*	*	*	Ely.rep.
27	*Epilobium spp.*					*		*		Epi.spp.
28	*Equisetum arvense* L.					*				Equ.arv.
29	*Erodium cicutarium* L.	*		*	*	*		*	*	Ero.cic.

30	*Euphorbia cyparisias* L.	*		*		*		*		Euph.cyp.
31	*Euphorbia helioscopia* L.	*	*		*	*		*	*	Euph.hel.
32	*Euphorbia humifusa* Willd.	*		*	*			*	*	Ehph.hum.
33	*Euphorbia spp.*	*		*	*	*	*	*		Euph.spp.
34	*Fallopia convolvulus* (L.) A.Löve	*	*	*	*	*	*	*	*	Fall.con.
35	*Fumaria officinalis* L.	*								Fum.offi.
36	*Galinsoga parviflora* L.			*	*					Gal.parv.
37	*Galium aparine* L.							*		Gal.apa.
38	*Geranium dissectum* Jusl.	*	*	*		*		*	*	Ger.diss.
39	*Geranium molle* L.	*				*	*	*		Ger.mol.
40	*Hibiscus trionum* L.			*	*	*	*	*	*	Hib.trio.
41	*Hordeum murinum* L.	*					*		*	Hor.muri.
42	*Lactuca serriola* L.	*	*	*	*	*	*	*	*	Lac.ser.
43	*Lamium amplexicaule* L.	*					*			Lam.amp.
44	*Lamium purpureum* L.	*	*	*	*		*	*		Lam.pur.
45	*Lathyrus aphaca* L.							*		Lath.apha.
46	*Cardaria draba*	*				*	*	*		Lepid.spp.
47	*Linaria vulgaris* Mill.				*	*				Lin.vulg.
48	*Lotus corniculatus* L.	*		*		*				Lot.cor.
49	*Medicago sativa* L.	*		*	*			*		Med.sat.
50	*Melilotus officinalis* L.			*		*		*		Mel.off.
51	*Mentha arvensis* L.	*		*						Men.arv.
52	*Papaver rhoes* L.		*	*	*	*				Pap.rhoe.
53	*Persicaria maculosa* L.			*	*			*	*	Plan.maj.
54	*Plantago lanceolata* L.							*	*	Plan.lanc.
55	*Poa pratensis* L.			*						Poa prat.
56	*Polygonum aviculare* L.	*	*	*	*	*	*	*	*	Pol.avi.
57	*Portulaca oleracea* L.	*	*	*	*	*	*	*	*	Por.oler.
58	*Ranunculus arvensis* L.								*	Ran.arv.
59	*Ranunculus repens* L.			*	*		*			Ran.rep.
60	*Raphanus raphanistrum* L.			*	*					Raph.raph.
61	*Rubus caesius* L.					*		*		Rub.cae
62	*Rubus ideous* L.	*	*	*	*	*	*	*	*	Rub.ide.
63	*Rumex crispus* L.	*	*	*	*	*	*	*	*	Rum.cris.
64	*Senecio vulgaris* L.	*	*	*	*	*	*	*	*	Sen.vul.
65	*Setaria pumilla* (Poir .)	*								Set.pum.
66	*Sinapis arvensis* L.	*	*					*	*	Sin.arv.
67	*Solanum nigrum* L.	*	*	*	*	*	*	*	*	Sol.nig.
68	*Sonchus arvensis* L.	*		*	*					Son.arv.
69	*Sonchus oleraceus* L.	*	*	*	*	*	*	*	*	Son.ole.
70	*Stachys annua* L.	*							*	Sta.ann.
71	*Stellaria media* (L.) Vill	*	*	*	*	*	*	*	*	Ste.med.

72	*Taraxacum officinale* Web.	*	*	*	*	*		*	*	Tara.off.
73	*Thlaspi arvense* L.	*								Thal.arv.
74	*Tragopogon pratensis* L.	*				*		*	*	Trag.pra.
75	*Trifolium aerum* Pollich.							*		Tri.aer.
76	*Trifolium pratense* L.							*		Tri.pra.
77	*Trifolium repense* L.	*		*	*	*	*	*	*	Tri.rep.
78	*Veronica agrestis* L.					*				Ver.agre.
79	*Veronica hederifolia* L.	*		*	*	*	*	*	*	Ver.hed
80	*Veronica persica* Poir.	*	*	*	*			*		Ver.per.
81	*Vicia cracca* L.	*	*	*	*			*	*	Vic.cra.
82	*Vicia sativa* L.	*		*		*		*	*	Vic.sat.
83	*Viola arvensis* Murr	*		*		*	*	*	*	Vio.arv.
84	*Xanthium strumarium* L.	*	*	*	*	*	*	*	*	Xan.str.

Table A2: Total species list recorded in vineyards of Kosovo in 2016 and 2017 and species traits. D – dicotyledons, M – monocotyledons; A – annual, P – perennial.

No.	Species	Life form	Family	D	M	A	P
1	*Achillea millefolium* L.	H,C	*Asteraceae*	*			*
2	*Alopecurus mysourides* Huds.	T	*Poaceae*		*	*	
3	*Amaranthus Blitoides* L.	T	*Amaranthaceae*	*		*	
4	*Amaranthus retroflexus* L.	T	*Amaranthaceae*	*		*	
5	*Anagallis arvensis* L.	T	*Primulaceae*	*		*	
6	*Anthemis arvensis* L.	T	*Asteraceae*	*		*	
7	*Aristolochia clematitis* L.	H	*Aristolochiaceae*	*			*
8	*Artemisia vulgaris* L.	H,C	*Asteraceae*	*			*
9	*Avena fatua* L.	T	*Poaceae*		*	*	
10	*Bifora radians* M. Bieb.	T	*Apiaceae*	*		*	
11	*Bromus sterilis* L.	T	*Poaceae*		*	*	
12	*Capsella bursa pastoris* L.	T	*Brassicaceae*	*		*	
13	*Centaurea cyanus* L.	T	*Asteraceae*	*		*	
14	*Chenopodium album* L.	T	*Chenopodiaceae*	*		*	
15	*Chenopodium ficifolium* Sm.	T	*Amaranthaceae*	*		*	
16	*Cichorium intybus* L.	H	*Asteraceae*	*			*
17	*Cirsium arvense* (L.) Scop.	G	*Asteraceae*	*			*
18	*Consolida regalis* S.F (Gray)	T	*Ranunculaceae*	*		*	
19	*Convolvulus arvensis* L.	G, Hli	*Convolvulariaceae*	*			*
20	*Conyza candensis* (L.) Cronq	T,H	*Asteraceae*	*		*	
21	*Cynodon dactylon* L.	G,H	*Poaceae*		*		*
22	*Dactylis glomerata* L.	H	*Poaceae*		*		*
23	*Datura stramonium* L.	T	*Solanaceae*	*		*	
24	*Daucus carota* L.	H	*Apiaceae*	*			*
25	*Echinochloa crus-galli* L.	T	*Poaceae*		*	*	
26	*Elymus repens* (L.) P.Beauv.	G	*Poaceae*		*		*
27	*Epilobium spp.*	/	*Onagraceae*	*		/	/
28	*Equisetum arvense* L.	G	*Equisetaceae*		*		*
29	*Erodium cicutarium* L.	T,H	*Geraniaceae*	*		*	
30	*Euphorbia cyparisias* L.	H,G	*Euphorbiaceae*	*			*
31	*Euphorbia helioscopia* L.	T	*Euphorbiaceae*	*		*	
32	*Euphorbia humifusa* Willd.	T	*Euphorbiaceae*	*		*	
33	*Euphorbia spp.*	/	*Euphorbiaceae*	*		/	/
34	*Fallopia convolvulus* (L.) A.Löve	Tli	*Polygonaceae*	*		*	
35	*Fumaria officinalis* L.	T	*Fumariaceae*	*		*	
36	*Galinsoga parviflora* L.	T	*Fumariaceae*	*		*	
37	*Galium aparine* L.	Tli	*Rubiaceae*	*		*	
38	*Geranium dissectum* Jusl.	T	*Geraniaceae*	*		*	

39	*Geranium molle* L.	T	*Geraniaceae*	*		*	
40	*Hibiscus trionum* L.	T	*Malvaceae*	*		*	
41	*Hordeum murinum* L.	/	*Poaceae*		*	*	
42	*Lactuca serriola* L.	H	*Asteraceae*	*		*	
43	*Lamium amplexicaule* L.	T	*Lamiaceae*	*		*	
44	*Lamium purpureum* L.	T,H	*Lamiaceae*	*		*	
45	*Lathyrus aphaca* L.	Tli	*Fabaceae*	*		*	
46	*Cardaria draba*	H, G	*Apiaceae*	*			*
47	*Linaria vulgaris* Mill.	G,H	*Plantaginaceae*	*			*
48	*Lotus corniculatus* L.	H	*Fabaceae*	*			*
49	*Medicago sativa* L.	H	*Fabaceae*	*			*
50	*Melilotus officinalis* L.	H	*Fabaceae*	*			*
51	*Mentha arvensis* L.	G, H	*Lamiaceae*	*			*
52	*Papaver rhoes* L.	T	*Papaveraceae*	*		*	
53	*Persicaria maculosa* L.	T	*Polygonaceae*	*		*	
54	*Plantago lanceolata* L.	H	*Plantaginaceae*	*			*
55	*Poa pratensis* L.	H,G	*Poaceae*		*		*
56	*Polygonum aviculare* L.	T	*Polygonaceae*	*		*	
57	*Portulaca oleracea* L.	T	*Portulacaceae*	*		*	
58	*Ranunculus arvensis* L.	T	*Ranunculaceae*	*		*	
59	*Ranunculus repens* L.	H	*Ranunculaceae*	*			*
60	*Raphanus raphanistrum* L.	T	*Brassicaceae*	*		*	
61	*Rubus caesius* L.	z,li	*Rosaceae*	*			*
62	*Rubus ideous* L.	n	*Rosaceae*	*			*
63	*Rumex crispus* L.	H	*Polygonaceae*	*			*
64	*Senecio vulgaris* L.	T,H	*Asteraceae*	*		*	
65	*Setaria pumilla* (Poir .)	T	*Poaceae*		*	*	
66	*Sinapis arvensis* L.	T	*Brassicaceae*	*		*	
67	*Solanum nigrum* L.	T	*Solanaceae*	*		*	
68	*Sonchus arvensis* L.	G,H	*Asteraceae*	*		*	
69	*Sonchus oleraceus* L.	T,H	*Asteraceae*	*		*	
70	*Stachys annua* L.	T	*Lamiaceae*	*		*	
71	*Stellaria media* (L.) Vill	T	*Caryophyllaceae*	*		*	
72	*Taraxacum officinale* Web.	H	*Asteraceae*	*			*
73	*Thlaspi arvense* L.	T	*Brassicaceae*	*		*	
74	*Tragopogon pratensis* L.	H	*Asteraceae*	*		*	
75	*Trifolium aerum* Pollich.	T,H	*Fabaceae*	*		*	
76	*Trifolium pratense* L.	H	*Fabaceae*	*			*
77	*Trifolium repense* L.	G,H	*Fabaceae*	*			*
78	*Veronica agrestis* L.	T	*Scrophulariaceae*	*		*	
79	*Veronica hederifolia* L.	T	*Scrophulariaceae*	*		*	
80	*Veronica persica* Poir.	T	*Scrophulariaceae*	*		*	

81	*Vicia cracca* L.	Hli	*Fabaceae*	*	*
82	*Vicia sativa* L.	/	*Fabaceae*	*	*
83	*Viola arvensis* Murr	T	*Violaceae*	*	*
84	*Xanthium strumarium* L.	T	*Asteraceae*	*	*