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Sustainable management of the main two Maltese indigenous grape varieties for winemaking

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Investing in your future

To my parents for all the dedication they showed throughout my life, and to all the growers of the Maltese indigenous vines for the devotion they put in their work.

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Abstract

Ġellewża and Girgentina, the main two Maltese indigenous grape varieties that are used for winemaking, are grown in small parcels of land with an average size just over 0.1 ha. Policies and regulations that influence the sector have been set up and this increased the need for studies to understand the current management practices and how can they be more sustainable.

Through interviews with 30 growers of the indigenous grape varieties it was found that most vines are trained as bush vines and cane pruned with 2 or 3 canes with about 5 to 10 buds in each. Nutrition is mainly given in the form of artificial fertilizer or organic pellets, but the timing is varied. Growers also have varied strategies for plant protection, mainly based on the use of sulfur and copper sulfate, and systemic fungicides. 14 growers also used insecticides, but the use of herbicides was not found to be common. Only 12 growers irrigated their vines and the water quality was found to be different from one location to another, with very high water conductivity, chlorides, and nitrates observed in some locations, mainly those close to Għajn Rihana.

Data obtained from sugar levels and yield of 2010, 2011, and 2012 harvests were analysed. Temperature, precipitation and wind speed data for those three seasons were also reviewed to understand the trends along the viticulture season. For both varieties, there was no significant correlation observed between yield and sugar levels in most seasons. The brix was not significantly different from one season to another in most scenarios considered but the yield for 2012 was found to be significantly higher from that of the two other seasons, most probably due to weather conditions. The average yield for Ġellewża was higher than the average yield for Girgentina in every season.

PCA analysis showed that the brix and yield data cannot be distinguished by location of vineyard.

A list of recommendations was presented to ensure that the management practices are improved and therefore prove that sustainability is the way forward for Maltese vineyards and winemaking.

Keywords: Ġellewża, Girgentina, indigenous vines, Mediterranean viticulture, irrigation water quality

1 Introduction

1.1 General introduction

The management of the main two indigenous varieties in Malta is by and large unexplored by scientific research. The agricultural practices related to these two varieties are currently based on traditional and indigenous knowledge that has been passed on from generation to generation while policies and regulations have been indirectly effecting the way these varieties can be grown and setting standards for the wine being produced from them for commercial purposes.

On the other hand, viticulture is a growing area of research in various winemaking countries and studies from other counties can give a direction to what research can be carried out in Malta to understand the management currently taking place and to make it more sustainable.

This study gives an overview of basic common practices in viticulture and upcoming sustainable practices that are being researched and also gives an overview of recent policies and regulations that have influenced the industry. Most importantly, this study investigates some of the practices being carried out in Malta and includes an analysis of the sugar levels and yields obtained recently. This gives a holistic, albeit rather general overview to the current situation in Malta, from which recommendations has been outlined to continue the improvement for a more sustainable management of the two main varieties.

1.2 Agriculture in Malta

1.2.1 An overview of the Maltese agriculture industry

The Maltese Archipelago consists of three inhabited islands, Malta, Gozo, and Comino, and some other uninhabited much smaller islands, which in all have a total surface area of 316 km^2 and a total population of about 450,000 people. Maltese agriculture faces great challenges due to the severe scarcity of land and the equally severe scarcity of water (Climate Change Committee for Adaptation, 2010), which is aggravated by the population density of about 1400 persons per kilometer, making it one of the most overpopulated countries in the world.

A great portion of agricultural land is on sloping ground, which is terraced with retaining walls made of limestone rubble. Some of these walls have been neglected and the loss of the rubble results in an increase of soil erosion. The majority of the agricultural land is not irrigated, resulting in a large amount of bare soil during the dry season, leading to further erosion. Furthermore, the short, heavy rainstorms which are common during the transition from the dry to the wet season result in increased runoff and erosion (Schembri, 1993).

The use of organic fertilizers such as farmyard manure is beneficial to local soil due to the very limited amount of organic matter it contains. This will reduce the need for inorganic fertilizers which are much more energy intensive to produce and can leach faster and are therefore not considered as a sustainable option. It is also uneconomical to use inorganic fertilizers when there is a surplus of animal manure available in Malta. The nitrate directive allows for the field storage of solid manure between 16th March and 14th October if the dry matter content is at least 30% (Vella & Kuecke, 2003).

87% of the agricultural parcels in the Maltese Islands are less than one hectare in area, and 99.7% are less than 5 hectares. Only 10.7% of tenants are below the age of 40, 46.7% are aged between 40 and 60 and 42.6% are over 60 years old (Vella & Kuecke, 2003).

In 2010, the agricultural land in the Maltese Islands was 12,940.1 ha, of which 88.5% were declared as utilized agricultural areas. Arable land accounted for 79.3% of the total utilized agricultural area, permanent crops accounted for 10.9% and the remaining 9.8% were used as kitchen gardens, as shown in Figure 1. The majority of land was used for the cultivation of forage crops which covered 5,552.8 ha, equivalent to 61.2% of the area.

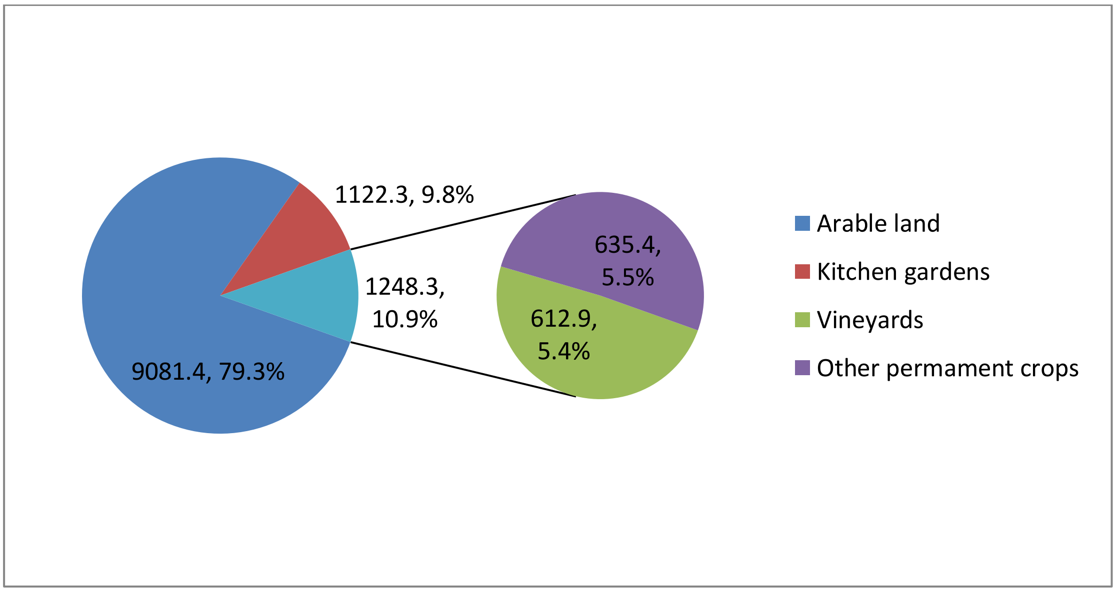

Figure 1 - A pie of pie showing the area in hectares and the percentage of the land uses in the utilized agricultural area

49.1% of all permanent in crops (equivalent to 5.4% of the total utilized agricultural area) in the Maltese Islands were vineyards (MCCAA, 2013). Other permanent crops present in Malta include peaches, olives and citrus trees. The total area under vines in the Maltese Islands is about 683.3 ha. 25.35% of this area is Girgentina grapes, covering an area of about 173.5 ha, while 13.35% of the area is Ġellewża grapes, covering an area of about 91.5 ha (Gambin, 2013).

Data collected by the World Bank (2013) shows that 34% of the agricultural land is irrigated, a value that has been increasing over the years, while the fertilizer consumption was 75.8 kg/ha in 2009, which is less than the value of 97.3 kg/ha recorded in 2003, and the value of 148.0 kg/ha recorded in 2006. The number of employees in the agriculture sector in Malta, including both the public and private sector, was 2.1% of the population in 2003 and decreased to just 1.1% by 2011, while the percentage of all the agriculture industry of the GDP (Gross Domestic Product) was just 1.9% in 2010, a value that has decreased from the 2.9% recorded in 2003 (World Bank, 2013).

1.2.2 Irrigation

Irrigated fields are mostly located in the northern and western regions of Malta where shallow groundwater is readily available from the perched aquifers (Vella & Kuecke, 2003). The most widespread sources of irrigation water are an extensive amount of boreholes which abstract water from the mean-sea level aquifers. Another source of irrigation water that will be brought about through the implementation of the Sewerage Master Plan that is set to generate sufficient treated sewage effluent for the irrigation of about 2090 ha of agricultural land (Vella & Kuecke, 2003). Some of the farmers also make use of harvested rainwater. The Malta Water Association (MWA) claimed that “there cannot be an effective and comprehensive water strategy without a clear agricultural policy” (MWA, 2013). This is because the agriculture sector consumed about 28 million cubic meters in 2012, which is the equivalent of the total production by the Water Services Corporation for the public water supply. The MWA also recommended that farmers should shift to a more sustainable source of water instead of groundwater extraction and therefore calls for an easier process that allows farmers to construct rural reservoirs for the collection and use of runoff.

Metering of boreholes was always a debated political issue in Malta and the process of metering started in November 2011 (B. Borg, 2011) and is still ongoing, since just 928 meters have been installed till the end of February 2013 (Mizzi, 2013) from the 3,500 agricultural boreholes (B. Borg, 2011) found in the Maltese Islands. The Committee on Climate Change for Adaptation had recommended that the process of over-extraction through misuse and abuse of boreholes is reduced as early as possible, especially by banning the use of domestic boreholes that are only used for recreational purposes. Furthermore, the committee had recommended that the metering of all groundwater abstraction should be in place by 2011 so that by 2012 the Government would be able to "establish pricing mechanisms for private groundwater extraction based on social, economic and environmental considerations in order to target a reduced level of private extraction from the current 21.5 million m^3 per year to 16 million m^3 per year (Climate Change Committee for Adaptation, 2010). To date, there are no pricing mechanisms for groundwater extraction. The Climate Change Committee for Adaptation (2010) recommended that incentives should be given to farmers to build or re-activate water catchment systems, to improve irrigation systems, and also to set long-term management strategies that increase soil organic matter. After the amount of water extracted from boreholes is obtained from borehole meters, the Government will determine appropriate quotas and sanctions to be applied for specific crop plans (MRRA, 2012b). The Malta Water Association however points out that the metering of registered boreholes will not give a complete picture because the non-registered (illegal) boreholes will not be metered (MWA, 2013).

1.2.2.1 Water contamination

Water pollution can occur through various sources and as a result of numerous activities, but agriculture remains one of the major concerns due to its wide spread activity and also because it is an industry which is itself dependent on good quality water. The main pollutants from agriculture are nutrients from fertilizers (especially nitrates), chemicals from pesticides and any other suspended matter that can enter water streams. In Malta, concerns for pollution are not only related to ground water but also the very sensitive and scarce wetlands as well as sea water, both of which can be contaminated through surface runoff and result in increased turbidity and nutrient enrichment which can lead to eutrophication.

Legal notice 343 of 2001 calls for the protection of waters against pollution caused by nitrates from agricultural sources (LN343, 2001) and it is based on the European Nitrates Directive CD91/676/EEC (ECC, 1991b), which has the objectives of reducing water pollution caused or induced by nitrates from agricultural sources and preventing further such pollution. This legal notice was then amended by LN233 of 2004. As part of this European directive, a code of good agricultural practice had to be developed, which is then implemented on a voluntary basis by farmers. Legal notice 233 of 2004 designated all of Malta as a nitrate vulnerable zone (LN233, 2004).

1.2.2.2 Recent projects about ground water in Malta

The sustainable management of environmental issues related to water stress in Mediterranean Islands was tackled in the MEDIWAT project, with a budget close to

1.5 million euros, mostly financed by the European Union. The partnership of this project included six Mediterranean countries, all having problems with water resource management, and Malta participated through the Malta Resources Authority (MEDIWAT, 2013). In one of the initiatives part of this project, Malta conducted an assessment of the environmental impact of artificial recharge of the aquifer system by highly polished treated water which is in line with the implementation of the Urban Wastewater Treatment Directive 91/271/EEC (ECC, 1991a). This pilot project showed that such system would require a sufficient availability of the treated effluent, a huge cost due to the electrical power and chemicals needed, and a rigid monitoring on the quality of water used for recharge as conventional biological treatment is not always effective in removing hazardous substances and this could lead to severe consequences in the aquifers (Sapiano, Schembri, & Brincat, 2013).

The University of Catania, CSEI Catania, and 'Agenzia Regionale per la Protezione Dell'Ambiente – DAP Ragusa' partnered with the Malta Resources Authority and the Water Services Corporation on a two year project called MORISO under the Italia – Malta 2007-2013 Cross-Border Cooperation Programme. The main objective of the project was to monitor coastal aquifers for water intrusion and pollution caused by agricultural activities (MORISO, 2013). The project involved the implementation of a groundwater monitoring network, the setting up of a GIS of water resources, and two pilot projects: one for an assessment of the impact of irrigation using saline waters and the other for developing a solar mobile water polishing plant. A conceptual hydrogeological model and a numerical groundwater model of the groundwater body in the island of Comino was set up in order to give a better understanding of how the groundwater system works with the scope of helping the management of the groundwater of the island of Malta, which is much more complex to model, but has similar characteristics. The MORISO project confirmed that pollution by nitrates is the most important issue affecting groundwater quality. Another important issue highlighted was overabstraction and salt intrusion in the mean sea level aquifer. There was no pollution by pesticides or heavy metals identified in any of the monitoring stations but the presence of arsenic and fluoride was found in specific sites, possibly due to geogenic origin (Sapiano, 2013).

1.2.3 The Maltese Code of Good Agricultural Practice (CoGAP):

The CoGAP covers all aspects of agricultural production, including animal husbandry, manure handling, fertilization, irrigation, and plant protection. Since Malta has transposed various EU Directives into the national legislation, including the Nitrate Directive (ECC, 1991b) and the Water Framework Directive (EC, 2000), the practices under these directives are obligatory, and so are practices by farmers that benefit from under agri-environmental measures. However, the CoGAP also lists other recommendable practices that are not obligatory (Vella & Kuecke, 2003).

The CoGAP notes that micronutrients liquid fertilizers are more effective if they are sprayed on the leaves when the pH value is above 7 since these are not available for update by the plants through the roots. The CoGAP also highlights the importance of good fertilizer storage and handling procedures to ensure safety and to protect the products from rainfall, excessive humidity and heat. It is suggested that the fertilizers are not stored within 150 m of a drinking water well or 300 m from the coast.

Fertilization planning is essential to ensure the appropriate use of additional nutrients and should take into consideration the nutrient demands of the crop, the current nutrients already available in the soil, the type and amount of chemical substance that will be applied, the nutrients already available in irrigation water, current regulations for fertilizer application and the best timing of application (Vella & Kuecke, 2003). In any case, fertilization should not exceed the limit of 170kg nitrogen per hectare per year as stipulated by the Nitrates Directive (ECC, 1991b). The CoGAP also recommends intercropping between permanent cultures to avoid bare soil and hence reduce soil erosion, and also to give the possibility of using nitrogen fixing plants that can also increase the nitrogen content in the soil. Mulching is also recommended to protect the soil from erosion and it can also improve the soil structure, and reduce evaporation of soil moisture. Soil cultivation should as much as possible avoid soil compaction, and in the case of fields with an inclination, tillage should be carried out across the slope (Vella & Kuecke, 2003).

The CoGAP also points out the need for good irrigation practices. It notes that irrigation is essential due to the very limited rainfall in the dry season, however excessive irrigation can lead to a depleted groundwater quality (Vella & Kuecke, 2003), and not to mention that it could be harmful to the crops as well. The quantity of irrigation water applied to a field should be therefore calculated on the requirements of the crop and the amount of water already available in the root zone. The reduction of water loss will also reduce the need for irrigation and therefore irrigation at peak sunlight should be avoided to reduce evapotranspiration.

Fertilization and irrigation practices can be combined together in what is known as fertigation, which refers to the application of fertilizers dissolved in the irrigation water. The CoGAP suggests that whenever possible, nutrients should be supplied through fertigation because it is more efficient than just spreading the fertilizer on the soil surface since not all of it will be dissolved and thus will result in the waste of substance and also contamination of surface and ground waters. Fertigation also allows the farmer to apply the amount of fertilizer needed at that particular stage of growth, rather than spreading it without knowledge of when that will be absorbed by the plant (Vella & Kuecke, 2003).

With regards to plant protection, the CoGAP suggests that plant protection products should only be used when entirely necessary and calendar spraying should be avoided, however this brings on a commitment for the farmer to check his crops regularly. The aim of plant protections should be to reduce infestation to ensure that there is no economic damage and not to kill all harmful organisms, unless there is the need to eliminate quarantine pests or their vectors (Vella & Kuecke, 2003). The CoGAP promotes the use of non-chemical plant protection as this is more environmentally friendly however it acknowledges that these require a higher level of expertise and can also be very expensive. The number of treatments and dose rates need to be taken into consideration to ensure that the pest infestation is eliminated and thus not allowing for resistant pest populations to develop. This can be achieved by using strategies of resistance management by utilizing products having different families of active substances (Vella & Kuecke, 2003). Good record keeping is recommended, now obligatory (MCCAA, 2013), and the precautions necessary when spraying need to be given priority.

1.2.4 Pesticides Use and Regulation

The competent authority for the authorization and regulation of pesticides in Malta is the Malta Competition and Consumer Affairs Authority (MCCAA) as per Pesticides Control Act of 2001 (CAP430, 2001) and the Malta Competition and Consumer Affairs Authority Act of 2011 (CAP510, 2011). Prior to 2011, pesticides were regulated by the Malta Standards Authority (MSA). The MCCAA regularly publishes the updated lists of approved and revoked plant protection products for Malta to ensure that only approved products are sold in agricultural shops and used by professional users. The MCCAA also offers training courses to professional users of plant protection products and is now aiming to have all professional users to be registered by the end of 2013 by attending the appropriate training course (MCCAA, 2013).

In a survey carried out by the National Statistics Office (NSO) in 2007, it was found that the area treated with plant protection products amounted to 62.7% of the area surveyed, but when considering specifically vineyards, 91.6% of the area was treated. Fungicides were the major form of plant protection products used, while herbicides and insecticides were used much less. The same study in found that an average of 2.1 kg/ha of fungicide were sprayed in vines (MCCAA, 2013). These products are generally applied by a knapsack or by tractor mounted sprayers. Fungicide use was dominated by sulfur with 92.5% by weight of active substance, while MCPA (2-methyl-4-chlorophenoxyacetic acid) was the most common active substance used in herbicides at 92.1%. There were 4 commonly used insecticide active substances that were found: Carbaryl (24.9%), Malathion (23.0%), Chlorpyrifos (20.2%), and Dimethoate (19.2%) (MCCAA, 2013).

The national action plan for sustainable use of pesticides issued in 2013 notes that the pesticide usage in Malta follows the typical pattern of the Mediterranean climate, thus having herbicide use at the beginning of the agricultural season, fungicide use throughout the year but peaking between April and July, while insecticides are mostly applied in the summer months (MCCAA, 2013).

Pesticide use is regulated under the European Directive 2009/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides (EC, 2009). The national legislation regulating the use of plant protection products is the Pesticides Control Act (CAP430, 2001) which also includes subsidiary legislations such as the list of active substances authorized for use in plant protection products (LN358, 2009), regulations for the maximum residue levels of pesticides in produce of plant and animal origin (LN14, 2009), regulations for activities concerning the professional use of toxic products (LN350, 2005), the implementation of Regulation (EC) 1107/2009 concerning the placing of plant protection products on the market (LN284, 2011), and the sustainable use of pesticides as regulated under 2009/128/EC (LN489, 2011).

The national action plan also looks into inspections of pesticide application equipment, prohibiting the use of aerial spraying, the protection of the aquatic environment and drinking water, handling and storage of pesticides and also the treatment of their packaging and remnants. It also looks into the promotion of integrated pest management and organic farming as methods for reducing the use of pesticides in Malta (MCCAA, 2013). The national action plan also emphasizes the importance of recordkeeping both for suppliers and users, and also the precautions needed to ensure adequate health and safety when using plant protection products.

1.3 Viticulture in Malta

1.3.1 History

Vine cultivation has been most likely introduced in the Maltese Islands by the first Phoenician settlers, and it has been cultivated along the years with improved methods that still showed signs of Phoenician origin, meanwhile viticulture flourished during the rule of the Order of St. John as the country began to produce its own wine and also export it to other countries (J. Borg, 1922). On the other hand, widespread vineyard destructions occurred in the eighteenth century due to the increased demand for cotton.

The destruction of vineyards in the Maltese Islands by phylloxera was reported in June 1919 in a number of vineyards in Gozo, and further destructions occurred in Malta a year later. Like elsewhere, as from early 1920s, American rootstocks were then used as these were tolerant to the aphid since they form calluses which prevent the ‘bleeding’ from the root wounds caused by phylloxera (Meekers, 2006). Furthermore, mildew was controlled using sulfur and Bordeaux mixture (J. Borg, 1922), which is a mixture of copper sulfate and slaked lime.

Borg (1922) stated that there were about 38 local varieties, including table grapes, of the European vine grown in the Maltese Islands but many were very similar to other varieties cultivated in the Mediterranean region and the variations could simply be due to the differences in soil and climate (J. Borg, 1922). It was a common practice in Malta up to the early 20th century to have a field blended with many grape varieties. The Maltese wines of the past was made from Girgentina and Ġellewża blended along with other unidentified white and red grapes that made the white (amber) and red (black) wines (Meekers, 2006).

The origins of Girgentina and Ġellewża are unknown. There is no information as to how long they have been in Malta or how they have arrived here. Some think that the Arab rulers brought them along from Spain, but it is also possible that these two varieties developed locally through evolution from chance seedling (Meekers, 2006). Scientific research indicates that these two varieties are not related to any other cultivar planted in Malta or in Europe (Giannetto, Caruana, La Notte, Costacurta, & Crespan, 2010). These two varieties have adapted to local climate and have been able to produce decent yields even in vineyards with no additional irrigation. Girgentina, referred to as *Insolja tal Ghirghenti* at the time, was well known for its extreme vigor and good yields, and also for the ability to keep the grapes in excellent condition till Christmas (J. Borg, 1922).

These two grape varieties are naturally low in sugar content, something with is not typical of grapes growing in hot climates, and can make wines at around 9% to 10% alcohol (Meekers, 2006).

The alcohol content can be theoretically increased through chaptalization, a process through which sugar is added to unfermented grape must. This process is referred to as enrichment in the EU, and there are strict guidelines of how much the alcoholic strength could be increased. The increase in natural alcoholic strength by volume for fresh grapes, grape must in fermentation, or new wine still in fermentation can be done by adding sucrose, concentrated grape must, or rectified concentrated grape must as indicated in the Council Regulation (EC) 479 of 2008 on the common organization of the market in wine (EC, 2008).

1.3.2 Current situation

Viticulture in Malta has been present for a long time; however it was only until recently that there has been interest in scientific research related to grapevine growing. This mainly came about with the Wine Act of 2001 (CAP436, 2001) that regulates the viticulture and oenology sector in Malta, and through research projects carried out at the University of Malta. The Viticulture and Oenology Unit was re-established in 2002 and has since then been functioning within the Agricultural Services and Rural Development Division (Department of Agriculture, 2013). Up till March 2013, this division fell under the portfolio of the Ministry for Resources and Rural Affairs (MRRA), and it is now under the portfolio of the Parliamentary Secretary for Agriculture, Fisheries and Animal Rights which works within the Ministry for Sustainable Development, the Environment and Climate Change.

According to official data provided by the Permanent Crops Unit within the Directorate of Agriculture, which data is then communicated to the European Union through Eurostat, there are about 2,100 farmers registered as vine growers with the Permanent Crops Unit, however this number include farmers who cultivate wine grapes of international varieties and wine grapes for personal consumption (Gambin, 2013).

The main two Maltese indigenous grape varieties are called 'Ġellewża' and 'Girgentina' and are not found in any other wine-producing country (MRRA, 2012a). Ġellewża produces reddish grapes that are usually used to produce rosé wines but can also produce red wines, while Girgentina produces white grapes that are used to produce white wines.

The wine fermented from these two varieties sometimes does not to reach the minimum level of alcohol as stipulated by Council Regulation (EC) 1493 of 1999 on the common organisation of the market in wine (EC, 1999), which was then repealed by Council Regulation (EC) 479 of 2008. This could be due to bad management practices that can be improved through further research. To tackle this problem, the Ministry for Resources and Rural Affairs (MRRA) has intended to produce a cultivation plan for these two varieties but this has not been completed so far. Currently, for the wines from these grapes to be certified as IĠT wines (the Protected Geographical Indication label for the Maltese Islands), the minimum natural alcoholic strength values are lower than those used for other international varieties (MRRA, 2012a).

The main research carried out on these varieties was part of the VOTIVVOM (Valorisation Of The Indigenous Vine Varieties Of Malta) project, as part of the EU Seventh Framework Programme. This project was coordinated by the Viticulture and Oenology Unit with the support of the Division of Rural Sciences and Food Systems at the Institute of Earth Systems. This research should lead to an ampelographic description of the two indigenous grape varieties. Sanitisation and micropropagation trials were carried out to produce healthy material for propagation for the production of virus free plants of Girgentina and Ġellewża, however, the results from this project have not yet been published (Gambin, 2013).

1.3.3 Green Paper about the Maltese Wine Sector.

The Ministry for Resources and Rural Affairs published a *Green Paper* on the Maltese wine sector in April 2012, with a focus on quality wines. Quality wines in this context have been defined as those having a Protected Denomination of Origin (PDO) and those having Protected Geographical Indication (PGI), and both categories of wines are classified as Quality Wines Produced in a Specified Region (QWPSR). These categories also include strict guidelines for cultivation, such as limits on the amount of grapes produced per hectare, to ensure uniform maturity and high content of sugar and aromas (MRRA, 2012a).

In the Maltese Islands, quality wines having a PDO denomination are labeled as DOK wines, which stands for *Denominazzjoni tal-Origini Kontrollata*, meaning Denomination of Controlled Origin. Those having a PGI denomination are labeled as IĠT wines, which stands for *Indikazzjoni Ġeografika Tipika*, meaning Typical Geographic Indication (MRRA, 2012a).

In 2012 there were sixteen registered commercial wine producers in the Maltese Islands, eleven in Malta and five in Gozo. Of these sixteen wineries, ten were registered for the production of Quality Wines while the other six were registered for the production of Table Wines (TW). Table wines do not need to satisfy any restrictions regarding yields or sugar levels, but those made from grapes grown in the Maltese Islands can also add “Produce of Malta” to their label (MRRA, 2012a).

The Quality Wines produced in Malta are mostly from international varieties, but there is also an increasing use of wines made from the two main indigenous grape varieties. The green paper suggests that the increasing presence of wine made from the indigenous varieties on the market of Quality Wines is a clear indication that the consumers are specifically seeking wines produced from the indigenous varieties (MRRA, 2012a).

The production of DOK and IĠT wines in the Maltese Islands is regulated by the "DOK Wines Production Protocols Regulations, 2007" (LN416, 2007) and "IĠT Wines Production Protocols Regulations, 2007" (LN167, 2007), both issued under the Wine Act of 2001(CAP436, 2001). These regulations include the definitions and technical specifications of the DOK and IĠT wines, along with the quality parameters needed for their respective classifications (MRRA, 2012a).

DOK wines are split into two main categories: DOK Malta and DOK Gozo, while the IĠT wines make up a single category: IĠT Maltese Islands.

The maximum production of wine allowed for the production of IĠT wines is 125 hl/ha for all varieties used in the white and rosé typologies and 120 hl/ha for red typologies. The minimum natural alcoholic strength required for the production of IĠT wines from Girgentina and Ġellewża is 9.5% vol. for use in all wine typologies except the "Liquer" wine typology and the minimum total alcoholic strength of finished wine ready for consumption should be 10.5% vol. (LN167, 2007). For the production of DOK Malta or DOK Gozo wines, the maximum yield allowed for Girgentina white wine or Ġellewża rosé wine is 91 hl/ha and the minimum natural alcoholic strength allowed is 10.0% vol., while for the production of Ġellewża red wine maximum yield of 84 hl/ha is allowed and a minimum natural alcoholic strength of 11.0% vol. (LN416, 2007).

Legal Notice 416 of 2007 also provides for special wine mentions, which are reserved for particular wines that comply with specific requisites that are laid out in the same regulations. The three special mentions are "Superior", "Rizerva" and "Estate".

DOK "Superior" wines are those which are made from grapes having a higher sugar concentration and therefore result in wines with an increased alcohol concentration.

To classify as DOK "Superior" wines, the white and rosé typologies must possess a minimum natural and total alcoholic strength of 12.0% vol. The red typology must have a minimum natural and total alcoholic strength of 12.5% vol. (LN416, 2007). DOK "Riżerva" wines are those which satisfy the "Superior" requirements but have also undergone a specific period of ageing in wooden barrels or in the bottle, before being sold.

Estate wines are those made from grapes that are cultivated in the vineyards that are managed by the winery itself. It is claimed that this method of cultivation ensures that the quality characteristics of the grapes are more controlled and a better wine is produced. In the Maltese Islands there are no estates with the indigenous grape varieties and therefore at present, estate wines cannot be produced from Ġellewza and Girgentina (MRRA, 2012a).

The *Green Paper* states that the production of commercial Table Wines to be sold for a competitive price is not viable in the Maltese Islands, due to the high labor costs and the small size of the vineyards, and therefore the focus should be on the production of Quality Wines, and in fact the production of the latter is increasing.

Through the *Green Paper*, the government also presented a number of proposals aimed to stimulate and encourage the improvement and development of the local wine sector. These include the need to increase consumer awareness through marketing campaigns, more detailed requirements for the use of an "Estate" mention, the representation of small wineries on the Wine Regulations Board, and better recognition of vine growers.

About ten million bottles of wine are consumed annually in the Maltese Islands and about two million are produced locally, thus the current Maltese production does not meet the demand and needs to be strengthened both in quantity and quality, by investment from companies and by introducing innovative and functional production techniques (ProMed, 2013).

1.3.4 Research

Research about agriculture in Malta has been very limited let alone research specifically about viticulture, mainly due to lack of funds and resources available. Some research projects are carried out at the Division of Rural Sciences and Food Systems within the Institute of Earth Systems at the University of Malta. Various agriculture student projects gave a very general overview of aspects related to viticulture, such as vineyard management (Felice, 2012), the effect of a seaweed fertilizer on vines (Mangion, 2005), fungal diseases associated with vines (Tabone, 2001), and the presence of foreign grape vine varieties in Malta (Sciberras, 2008). Other related studies to the field included an investigation of the water holding capacity of Maltese soils (Galea, 2003) and the quality of irrigation waters (Farrugia, 2000).

1.4 Articulation of the research problem

The sustainable management of these vines, as with any other environmental resource, does not only depend on environmental considerations, but also on economic and social issues that need to be considered to ensure that in the long term the management remains viable for all stakeholders without affecting negatively other people and the natural resources.

This project will consider various factors that affect the vines; and their effects on yield and sugar content levels, while keeping into consideration principles of sustainability. Some of these factors are not influenced by management practices, such as: locality, altitude, quality of irrigation water, rain, and temperature. Other factors will depend on the specific management practice of the vineyard, such as: irrigation method, pruning technique, pesticide use, and choice of fertilisation. Due to various limitations, other factors that also affect the vines such as soil type, were not analysed in this project but were still considered in the literature review.

This study is aimed to give a better understanding of the current local scenario related to Maltese vineyards of the main two indigenous varieties. It will fill-up gaps of knowledge that are present because different entities collect separate information and sometimes do not consider a holistic approach. Through the analysis of the data collected and review of related scientific literature, this research will propose suggestions of how the local Ġellewża and Girgentina vineyards can be managed more sustainably.

This research will therefore act as a tool to government authorities, producer organisations, and local companies; for them to give better advice to local farmers. It will also be useful to policy makers to understand better the present situation and identify the aspects that need to be tackled for further improvement.

1.5 Aim and objectives

The aim of this work is to give a general overview of the current management practices of the main two indigenous varieties in Malta, identify what practices can be improved and give recommendations to make them more sustainable.

To achieve this aim the following objectives were set:

- Review the current situation in the agricultural sector in Malta, including policies and projects that are influencing the practices.
- Give a general overview of viticulture research from similar climates that can indicate what the best practices that can be considered locally are.
- Conduct interviews with local growers of the two varieties to understand what field practices and their opinion about the future of the indigenous vines in Malta.
- Gather weather data and harvest data for three consecutive seasons and identify trends that can indicate how the yield and sugar levels of these varieties can improve.
- Using a holistic approach, list recommendations of how the management of Ġellewża and Girgentina can be more sustainable.

2 Literature Review

2.1 *Vitis vinifera,* the European grapevine

Grapevines are commonly grouped in the genus *Vitis* in the family Vitaceae. *Vitis vinifera* is the only species of the family that has an important economic role due to the production of fresh and desiccated grapes, juices, and wine (ProMed, 2013). Recently, *Vitis labrusca* has also been used to make wine, while *Vitis berlandieri*, *Vitis riparia*, and *Vitis rupestris* are used as crosses to resist different fungal diseases (ProMed, 2013).

The European vine can thrive in various soil types, as long as it has well-drained subsoil and is free from stagnant humidity. It shows more vigor and higher yields in deep, relatively moist, porous soils but can also live on rocky ground and in relatively dry conditions (J. Borg, 1922). The vine is a perennial plant with the longest life cycle of all cultivated plants and have been cultivated according to local and old habits, which somewhat limit technical innovations. It is only when major biological or economic crisis occur that new management techniques are mostly implemented (ProMed, 2013). Most grapevine cultivars reproduce by self-pollination, and wind and insect pollination have little significance (Jackson, 2000). Vine death was mainly caused by *Armillaria mellea*, a pathogenic fungus which causes root rot, but recently various vines have been killed by Esca disease, which is a grapevine wood disease caused by fungi (ProMed, 2013).

The preferred habitats of wild *Vitis vinifera* were in the mild humid forests south of the Caspian and Black Seas and adjacent Transcaucasia, along the northern Mediterranean, and in central Europe along the Danube, Rhine, and Rhone river valleys (Jackson, 2000). The Mediterranean area and the Near East are in fact the area from which *Vitis vinifera* origined some 7 million years ago, while introductions in the Mediterranean basin date back to 7000 to 4000 BC (ProMed, 2013). While the vine can be found in a wide range of climates and can be found in more than 100 countries, it cannot be grown between 30°N and 30°S because due to the climatic conditions found within these tropical and subtropical regions, the plants rest with difficulty or do not rest at all (ProMed, 2013).

The International Organization of Vine and Wine has estimated that the total area of vineyards in the world (including areas not yet in production or harvested) was about 7.528 million hectares in 2012 (OIV, 2013), a value which has decreased in the past few years due to the decrease of vineyard area in Europe. However, the European continent still has the largest vineyard area in the world, which is about 38% of the global vineyard cover (Fraga, Malheiro, Moutinho-Pereira, & Santos, 2013). Wine production in 2012 was about 10% lower than in 2011 and the International Organization of Vine and Wine claims that the lower supply and higher prices for wine are affecting more intensively the cheapest product (OIV, 2013).

2.1.1 Rootstocks

Rootstocks from *V. rupestris* showed acceptable resistance to lime-induced chlorosis and was observed to root deeply, which also made it somewhat drought tolerant on deep soils but not suitable for shallow soils (Jackson, 2000).

Rootstocks were introduced to Europe after the phylloxera invasion, an insect (order: hemiptera) which spread through vineyards and destroyed large areas of sensitive cultivars (Arrigo & Arnold, 2007). The use of rootstocks also allow for cultivars to be grown in soils that would otherwise be damaging to the vine's own root system for some other reason. Rootstocks can provide an adaptation to humidity, dry clay soils, dense loam, or deep, dry, sandy soils. Some can also offer nematode resistance while others can provide tolerance to drought, active lime or salt (Jackson, 2000). Rootstock selection thus requires an in-depth analysis of each rootstock's benefits and deficits and the decision needs to be taken with great caution considering that once a rootstock is chosen, it becomes a permanent component of the vineyard until replanting (Jackson, 2000).

The rootstocks most adapted to Sicilian pedoclimatic conditions are the hybrids *Vitis berlandieri* × *Vitis rupestris*. In the eastern part of the island, 140Ru. is widely used in soils rich in limestone and in warmer habitats , while 1103P. is usually used in recently established vineyards with potential salinity problems. There rootstocks are ideal because of their vigor, stress-resistance and similarity to almost all cultivars (ProMed, 2013).

2.2 Vineyard practice

Vineyard management is aimed to maximize fruit yield of the desired quality. This can be achieved by different practices that include good fertilization and plant nutrition, pest management, training and pruning.

2.2.1 Vineyard establishment

The setting up of a vineyard has a high initial cost and requires a lot of preparations as well as crucial considerations, as subsequent changes are then even more costly, if not impossible. Therefore, a detailed feasibility study is important before any other step in vineyard establishment to ensure that the planting can produce satisfactory crops that can be sold at a reasonable price for a suitable period. One also needs to keep in mind that there is an interval of about three years between planting and the first financial return, and that this might create the need for a large initial interest burden. The costs of establishment are usually higher in cold regions and the annual production costs are up to ten times greater in cold regions when compared to hot regions (Boehm & Coombe, 1992).

An essential initial consideration is the land suitability, both in terms of geographical location and topography and also aspects related to the soil. This should also include an assessment of the water availability and quality, especially in relation to salinity. Other aspects that need to be planned include the variety to be planted, the trellis design and irrigation layout (Boehm & Coombe, 1992).

Soil preparation before planting new vineyards may be needed to ensure that the soil texture, compaction, and drainage conditions are sufficient and any nutrient deficiencies and toxicities are tackled. The most important aspect in any scenario is the provision of sufficient drainage and soil loosening to allow for root development (Jackson, 2000) and this can be done by ripping (Boehm & Coombe, 1992).

If the soil had vines planted, extra care must be given to possible diseases present in soil, especially nematodes. Fumigation of old vineyard land prior to replanting is recommended (Boehm & Coombe, 1992).

2.2.2 Training and pruning

Training refers to the development of a permanent vine structure and the location of renewal wood, in a way that the shoot growth is controlled and occurs in the desired direction (Jackson, 2000). Renewal spurs are short cane segments which are kept on the vine to produce canes from which shoots may originate in the year after. Replacement spurs are used to reposition the wood closer to the head or cordon. Vine support can be used to help the vine training system and this is usually in the form of a trellis.

Canopy management involves the positioning and maintaining the growing shoots and their fruit in a microclimate that is optimal for grape quality, inflorescence initiation and cane maturation (Jackson, 2000).

Pruning is a technique that is used to partially and selectively remove canes, shoots, wood, and leaves, or sometimes even roots, to obtain the goals of training and canopy management, usually by removing the excess shoot growth before the start of the new growth season. Furthermore, during the season, further thinning can be done by removing whole or parts of flower and fruit clusters to improve the berry microclimate and leaf area/fruit balance (Jackson, 2000).

Heavy pruning of vines grown on relatively nutrient-poor dry soils can direct photosynthetic capacity to fully ripen a restricted fruit load. However, one should be cautious as severe pruning will result in excess vegetative growth rather than less. Therefore, pruning should be done in a way to balance the canopy size and position in a manner to sufficiently sustain the crop to its optimal state of ripeness, ideally by avoiding insufficient or excessive leaf cover that will decrease fruit quality and yield (Jackson, 2000).

The absence of pruning allows for the rapid development of the leaf canopy and the initiation of fruit development, but growth will then be limited by the excessive carbohydrate demands during fruit maturation. The berry maturation is often delayed, and the sugar content and fruit quality are reduced but the yield can be increased by up to two and a half times of that of normally pruned vines. The yield may also be eventually reduced heavily in non-pruned vines due to diminished inflorescence initiation and reduced nutrient reserves (Jackson, 2000).

Vines grown on relatively nutrient-poor soils often also experience water stress and therefore the vine potential for vigorous growth needs to be restrained. A technique used to tackle this is by having dense plantations that allow for competition. This allows the vines to produce fine roots that are more able to extract the nutrients and some of these roots may also grow deep and reach subsurface water. On the other hand, wide spacing of vines, usually to allow for farm equipment to be used, have encouraged vigorous growth. In these cases the vine growth needs to be appropriately directed, such as by trellising systems, rather than pruned away (Jackson, 2000).

Spur pruning is more adapted to mechanical harvesting than cane pruning and it is also easier to be done by inexperienced pruners (Jackson, 2000).

As training systems are generally related to the origin of the bearing wood, can be generally classified as either head trained or cordon trained. Head training positions the canes or spurs that generate the fruit-bearing shoots outward on a swollen apex, or as several outward positioned short arms at the trunk apex (Jackson, 2000). Cordon-training allows for the bearing shoots to emerge somewhat equidistantly along the upper portions of the trunk, referred to as the cordons.

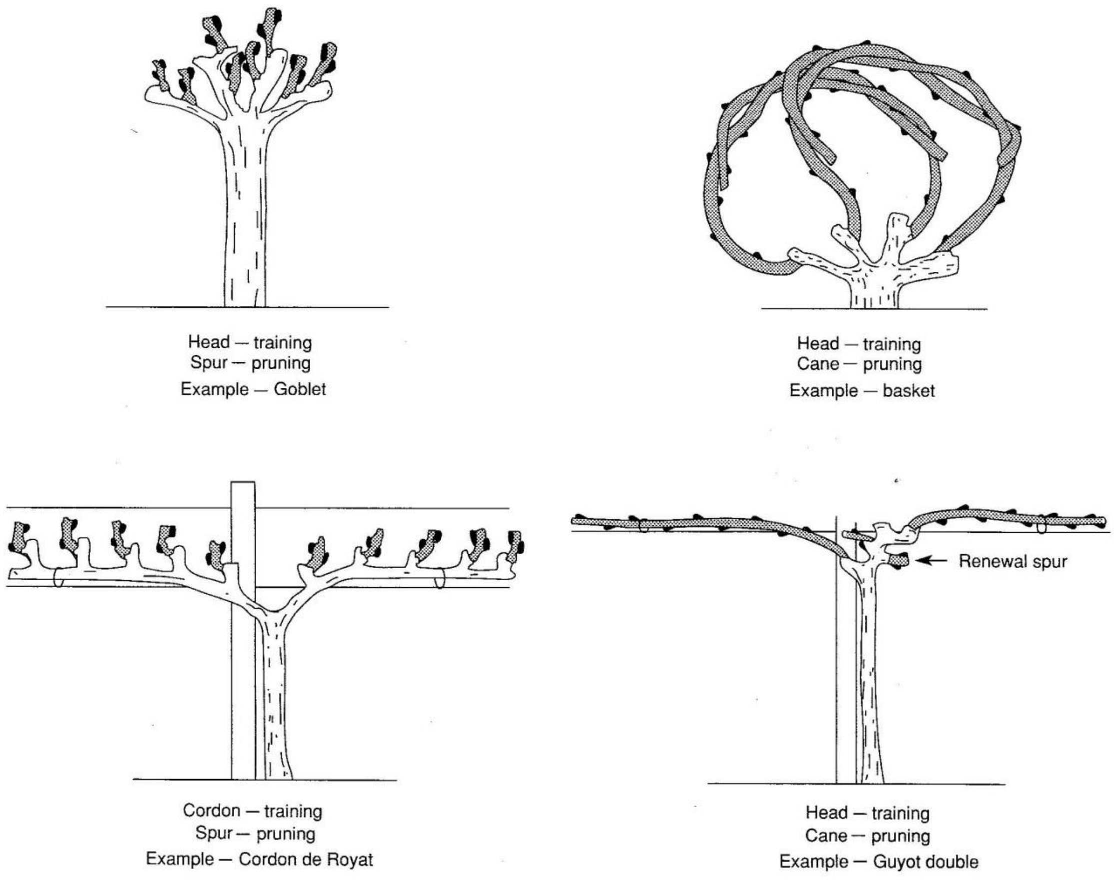

Figure 2 - Different training systems. Un-shaded areas represent old wood, shaded areas represent bearing wood, and black areas buds (Jackson, 2000)**.**

Head training is simple and inexpensive to develop as it does not require the use of a trellis and can also be easily maintained since the bearing shoots of one season can frequently be used to provide the bearing wood for the next season. Head training is suitable for vines planted in soils of low fertility and limited water availability (Jackson, 2000). The main disadvantage associated with head training is the tendency for shoot crowding, which results in undesirable fruit, leaf, and cane shading, and also canopy humidity which promotes disease development. In contrast to head training, cordon training positions the bearing wood horizontally along the upper portion of an elongated trunk either in one direction or both directions. The cordons need to be supported with wires and trellising systems to hold the weight of the shoot system and the fruit. The advantage of the cordon system is that the horizontal positioning reduces apical dominance and the bearing wood are uniformly spaced along the cordon, thus allowing for a canopy microclimate ideal for optimal fruit ripening and higher yields due to higher rates of photosynthesis, more fruitful buds, and more nutrient reserves in the wood structure of the vine (Jackson, 2000). This system is also the most suitable for mechanical harvesting as the fruit would be located in one zone of the vine. The disadvantages of a cordon system include the higher costs for a trellis support system, and the requirement for skilled pruners to establish such system with strategically positioned spurs or canes (Jackson, 2000).

The pruning residues have been usually considered as waste that needed to be disposed of, but lately have been considered as an opportunity for generating additional revenue and a way of generating energy from the ligno-cellulosic biomass, which adds up to at least one oven dry ton (odt) per hectare (Spinelli, Magagnotti, & Nati, 2010). There are specific machines that can be used to collect the pruning residues, generally quite light and inexpensive and suited to operate in the limited spaces offered by most vineyards. Some pick up, shred and collect the residue while others have balers that can pick up the residue, compact it into units of regular size and shape, and tie the bale for later collection. Bales are easier to store but cannot be fed to automated boilers unless they are further processed into chips (Spinelli *et al.*, 2010) . Spinelli *et al*. (2010) concluded that shredding the residue and collecting it into simple dumping bins is the most effective method for recovery. It was also noted that the economic viability of recovering vineyard pruning residue depends on the way the avoided costs of residue management are accounted for and on how these benefits are distributed between vineyard, owners, harvesting contractors and biomass users (Spinelli *et al.*, 2010). The heating value of vineyard pruning residues is slightly lower than that of forest fuels and the application of pesticides does not result in any significant contamination with noxious chemicals, because the chemical residues are mostly weathered away before the pruning residues are collected (Spinelli, Nati, Pari, Mescalchin, & Magagnotti, 2012).

2.2.3 Canopy management

Canopy management involves practices to control the leaf and shoot system growth in vines which have high vigor so as to reduce the increased within-canopy shade and thus improve production and/or wine quality, reduce disease incidence, and facilitate mechanization (Smart, Dick, Gravett, & Fisher, 1990) . In the Mediterranean region, the light is not usually a limiting factor except in cases where there is elevated vine vigor which increases the number of shaded leaves (Laget, Tondut, Deloire, & Kelly, 2008).

A range of techniques can be applied to alter the position or amount of leaves, shoots, and fruit in space, such as winter and summer pruning, shoot positioning, leaf removal, shoot vigor control, and use of improved training system (Smart *et al.*, 1990).

The results obtained by Smart *et al*. (1990) show that canopy management for dense canopies can improve both yield and quality, and therefore contradict the common opinion that high yield causes reduced wine quality.

2.2.4 Irrigation

Good irrigation will allow for grape cultivation in arid and semi-arid regions and can facilitate the production of premium quality grapes but if used excessively, irrigation can reduce the fruit quality and impact negatively cane maturation and on the other hand, water stress can reduce fruit set, berry size, and inflorescence initiation and development (Jackson, 2000).

Regulated Deficit Irrigation (RDI) is an irrigation scheduling technique that was originally developed for fruit orchards and has also been used for winegrape production by applying the deficit period shortly after fruit-set, in order to reduce shoot growth and berry early development (Santesteban, Miranda, & Royo, 2011). Santesteban *et al.* (2011) tested RDI strategies in 'Tempranillo' vineyards in semiarid areas of Spain and concluded that the harvest quality had been improved as the RDI berries had lower acidity and an increase in anthocyanin and phenolics concentration.

2.2.4.1 Water Quality and Salinity

Generally salt toxicity develops only under arid and semiarid conditions. The concentration of salts in the upper soil horizon is increases as water moves upwards by capillarity due to evaporation from the soil surface (Jackson, 2000). Salt accumulation decreases water availability by decreasing soil water potential and increasing the force required by roots to extract water.

The most common toxic salts found in water are borates and chlorides and grapevines are especially sensitive to chlorides which contribute to leaf chlorosis, thus resulting in leaf burn that reduces the photosynthetic capabilities and lead to undesirable physiological effects, such as delayed fruit maturation, smaller berry size, and reduced sugar accumulation (Jackson, 2000). Sodium accumulation can disrupt the soil structure and permeability and can also result in the displacement of calcium and magnesium from the soil. The exchange of divalent cations with monovalent sodium ions weakens the association between clay particles that help generate soil-aggregate formation, leading to dispersion. This can result in a claypan which makes the soil impermeable to water. Sodium can also contribute to a rise in soil pH, which results in the release of caustic carbonate and bicarbonate ions into the soil (Jackson, 2000).

2.2.5 Fertilization

Combined fertilization and irrigation, referred to as fertigation, is an effective way to regulate vine growth and grape quality, especially because the availability of NPK fertilizers is increased by fertigation and this is reflected in analysis performed on fruit and petioles (Bravdo & Hepner, 1986). The appropriate use of fertigation to regulate vine growth requires the knowledge of both the factors that affect water and nutrient availability and their effects on the various stages of vine growth (Jackson, 2000).

Fertilizer should be added near the end of the irrigation session so that the fertilizer is not flushed out of the root zone by the irrigation water itself (Jackson, 2000).

The main three macronutrients needed are nitrogen, phosphorus and potassium. The vines also need a considerable amount of calcium, magnesium, and sulfur. The micronutrients are only required in trace amounts and these include boron, chlorine, copper, iron, manganese, molybdenum, and zinc (Jackson, 2000).

2.2.5.1 Nutrient availability

Soil pH plays an important role in nutrient availability, and most soils are buffered to a narrow pH range which depends on various chemical and geographic aspects such as parent rock material, degree of weathering, and amount of organic content. In calcareous soils such as those in the Maltese Islands, the primary buffering salts are calcium carbonate, $CaCO_3$, and calcium hydrogen carbonate, $Ca(HCO_3)_2$. This makes the soil alkaline and limits the availability of iron, manganese, zinc, copper, and phosphorus ions, as shown in Figure 3:

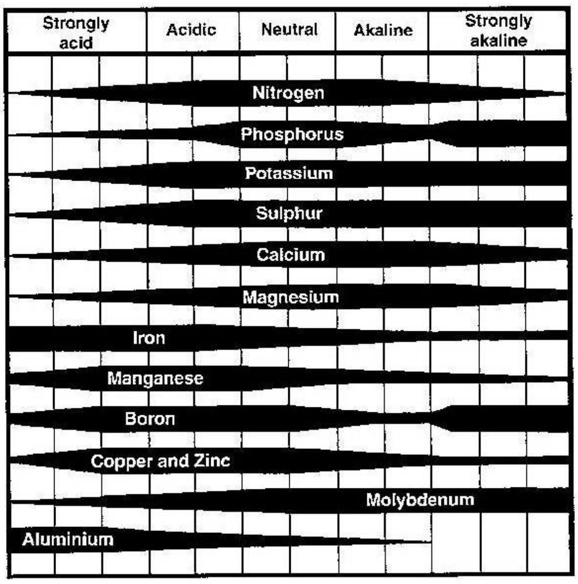

Figure 3 - Effect of pH on relative availability of nutrient elements (Dry & Coombe, 2004)

Elemental sulfur or calcium sulfate (gypsum) can be used to treat alkaline and sodic soils. Sulfur is microbially oxidized to sulfuric acid in the soil, neutralizing hydroxides while calcium sulfate both neutralizes hydroxides and permits sodium leaching by displacing it from soil colloids and carbonates (Jackson, 2000), however this might have a limited effect in Maltese soils due to their high buffering capacity.

2.2.5.2 Organic fertilizers

The use of manure in vineyards was a common practice in the past but this has been gradually replaced by the use of inorganic fertilizers, however, sustainability concerns related to the energy from fossil fuels needed to produce the inorganic fertilizers (Steenwerth & Belina, 2008) and the reduction of organic matter in the soil have encouraged the increase in the utilization of organic fertilizers (Jackson, 2000).

Well-matured animal manure is a good source of slowly released nutrients and humic material, and it also increases the activity of nitrogen-fixing bacteria, which is usually decreased by the application of inorganic nitrogen fertilizers (Jackson, 2000).

Humic materials are primarily made up of refractory organic compounds which form colloidal particles that bind with clay colloids, and together with cations such as Ca^{2+} and Fe^{3+}, they form stable aggregates which results in the ideal crumb structure of soil (Jackson, 2000). Humus is also an important habitat for soil microorganisms which are the main food source of invertebrates such as earthworms that are needed to improve soil porosity, thus increasing soil aeration and water penetration (Jackson, 2000).

Apart from animal manure, another convenient source of organic matter is through the use of green manures, which can act as groundcovers and also become composted to add nutrients. The process of green manure involves growing a crop and plowing it under while it is still green. The nitrogen content in the crop would then be enough to promote its rapid decay without limiting the nitrogen supply available for vine growth (Jackson, 2000). The use of leguminous crops is appropriate as green manures as they form associations with nitrogen fixing bacteria, such as *Rhizobium*. However, the inclusion of legumes in semi-arid tropics do not necessarily increase the nitrogen content because it depends on various management practices as nitrogen fixing is reduced with increasing amounts of mineral nitrogen in the soil and in drought (Wani, Rupela, & Lee, 1995). Using Trios 102 and Merced Rye as cover crops in California's Mediterranean climate, Steenwerth and Bellina (2008) found that microbial biomass nitrogen (MBN) was greater where these cover crops were used when compared to cultivated areas. Soil nitrate was greater in cultivated soils while soil ammonium was greater in cover crop treatments, and potential nitrification, nitrogen mineralization and denitrification was 2 to 4 fold greater in cover crop treatments, thus confirming that cover crops supports greater MBN and increased the microbiological functions of nitrification and denitrification (Steenwerth & Belina, 2008).

One of the most reported disadvantages of cover crops in Mediterranean non-irrigated vineyards has been the concern of excessive water competition between the cover crop and the vine (Lopes, Monteiro, Machado, Fernandes, & Araújo, 2008). Tesic *et al*. (2007) showed that soil moisture is decreased with increasing floor cover and did not observe an effect of floor cover treatment on the amount of organic carbon present in the soil. Petiole analysis also showed lower petiole nitrogen and magnesium levels in complete cover than those in bare treatment. In the third and fourth seasons, complete cover had lower yield, lower cluster number, and lower berry weight than in partial or no cover. The authors recommended to keep the cover mowed to decrease the water requirements, the use of species that are not characterized by intensive spring growth, the use of mulches as they provide the highest soil moisture conservation of all floor covers, the use of drought-tolerant rootstocks, and the increase of water amounts during critical stages (Tesic, Keller, & Hutton, 2007). Results obtained by Lopes *et al.* (2008) carried out in a Cabernet Sauvignon slopping non-irrigated vineyard in Portugal showed that cover cropping reduced the leaf water potential from bloom to mid-ripening, and after the third season this had resulted in a significant reduction in vegetative growth which lead to an improved grape composition by reducing titratable acidity and increasing berry skin total phenols and anthocyanins, and did not affect vine yield or berry sugar accumulation.

2.2.6 Grapevine diseases and pests

Grapevines are damaged by many living organisms which can range from fungal, bacterial, and viral pathogens to various insect and mite pests, rodents, and birds (Jackson, 2000).

Jackson (2000) identifies a number of species which act as pathogens and cause disease and the main fungal, bacterial and nematode pathogens are summarized in Table 1, Table 2, and Table 3:

Table 1 - A list of fungal pathogens and the corresponding diseases they cause

Fungal Pathogen	**Disease caused**
Botrytis cinerea	Botrytis bunch rot
Uncinula necator	Powdery Mildew (Oidium)
Plasmopara viticola	Downy Mildew (Peronospora)
Eutypa lata (Eutypa armeniacae)	Eutypa Dieback

Powdery and downy mildew are both of American origin and were noted for the first time in Europe in the 19th century (ProMed, 2013).

Table 2 - A list of bacterial pathogens and the corresponding diseases they cause

Bacterial Pathogen	**Disease caused**
Agrobacterium vitis	Crown Gall
Xylella fastidiosa	Pierce’s Disease
Acholeplasma sp. (e.g. elm yellow disease group 16SrV)	Yellow Diseases (e.g. flavescence dorée)

Table 3 - A list of nematode pathogens and the corresponding diseases they cause

Nematode Pathogen	**Pathogen characteristic**
Meloidogyne spp. (root-knot nematodes)	Sedentary endoparasites, penetrate young feeder roots
Xiphinema spp. (dagger nematodes)	Migratory nematodes, feed on epidermal cells near the root tip

Insect and mite pests include phylloxera (*Daktulosphaira vitifoliae*), leafhoppers, tortricid moths (such as *Lobesia botrana* which is found in southern Europe), and spider mites (such as the yellow spider mite *Eotetranychus carpini* which is the primary species in Mediterranean parts of France and Italy) (Jackson, 2000).

2.2.7 Disease and pest control

A sustainable approach towards the control of pests and disease is through integrated pest management (IPM). Aimed to reduce pesticide use by having multiple ways of control, this strategy combines the expertise of specialists from various fields including plant pathology, economic entomology, plant nutrition, weed control, and soil science (Jackson, 2000).

Apart from the use of chemicals, pest control can also be tackled through biological control, in which predators of insect pests are used as regulators of the pest population.

2.2.8 Tillage and weed control

Tillage has been the principal method of weed control; but was reduced with the development of herbicides. It is difficult to identify a control system that would be ideal for all situations, as tillage disrupts the structure of the soil while herbicides have been an environmental concern for the past years. Other methods of weed control include the use of mulches and cover crops. Cover crops are beneficial because they can be a source of organic matter as already mentioned earlier, however they need to be managed well to act as effective weed control. Weed control in vineyards can be effective by using cover cropping since vines are perennial crops and therefore resident vegetation can be dealt with by using selective herbicides or timely mowing to suppress the seeding of weeds, in which case the number and time of the mowing need to be adjusted to vegetation growth and species composition every year (Monteiro *et al.*, 2008). Cover crops can also limit soil erosion and improve water conservation by reducing water runoff (Jackson, 2000) and by limiting soil compaction and improving soil porosity (Monteiro *et al.*, 2008).

It is useful to have studies which establish which are the most adapted cover crops for the region or country in question (Monteiro *et al.*, 2008), as these would make them more effective and easier to manage. Both permanent resident vegetation and permanent sown cover crops can be used (Lopes *et al.*, 2008).

Mazzoncini *et al*. (2011) studied the interactions of tillage systems, nitrogen fertilization and cover crops in Italy. It was found that no-tillage systems are better than conventional tillage for the conservation and increase of soil organic carbon and total nitrogen content. Conventional tillage requires higher nitrogen fertilization rates and the introduction of highly productive cover crops to reach results similar to those obtained under no-tillage practices (Mazzoncini, Sapkota, Bàrberi, Antichi, & Risaliti, 2011).

Carbon and nitrogen accumulation in soil increases the sequestration of atmospheric carbon into the soil, thus reduces the negative effects of cropping on climate change (Mazzoncini *et al.*, 2011) .

2.3 Organic viticulture

The desire for the production of superior quality fruit and concerns for environmental sustainability have motivated producers to use natural viticulture practices, including organic and biodynamic systems. Other motivators include personal lifestyle choices of producers, human health considerations, business longevity, and marketing (Bekkers, 2011). Gradually, organic systems are being adopted by larger, more sophisticated and well-recognized businesses and not just small producers (Bekkers, 2011).

The first forms of organic viticulture in Europe date back to the 1950s, as Switzerland and Germany started applying the principles of organic agriculture to viticulture. However, the development was slow as many were concerned about loss of yields through diseases such as those caused by *Plasmopora viticola* (downey mildew) (Willer, 2008).

A major development in the history of European organic viticulture was through the European funded project ORWINE (Organic Viticulture and Wine-making: development of environment and consumer friendly technologies for organic wine quality improvement and scientifically based legislative framework), which aims at developing the legislative framework for wine for organic viticulture (Willer, 2008).

Studies in organic viticulture are also looking into the possibility of using milk, its components and by-products for controlling powdery mildew as an alternative or in combination to the use of sulfur (Johnston, Penfold, Marsohner, Pike, & Santiago, 2012).

2.4 Climate and weather

2.4.1 Scales of climate

There are three special scales of climate that are important to consider in vineyard management. These are the macroclimate, the mesoclimate, and the microclimate.

The macroclimate defines the climate of a region ranging from tens to hundreds of kilometers (Dry & Coombe, 2004), thus for the Maltese Islands one can infer that the macroclimate is the same in all locations.

The mesoclimate is usually specific to a particular vineyard as it can vary with geographic characteristics. Elevation is an effective source of variation as mean temperature decreases by 0.5°C to 0.6°C for every 100m increase (Dry & Coombe, 2004). It can also lead to more exposure to wind. The proximity to large bodies of water is also considered when analyzing the mesoclimate (Dry & Coombe, 2004) and so the distance of a vineyard in Malta to the sea is an important consideration, due to difference in temperature changes and salt spray. The slope of a vineyard and adjacent topography can affect the wind and light exposure and thus they also affect the mesoclimate (Dry & Coombe, 2004). Mesoclimate differences can result in the grape ripening of different areas of Malta to occur in a prolonged period.

The microclimate is that within and closely surrounding a plant canopy. It affects the grape ripening process and disease control and it is mostly affected by the vineyard management rather than by the location of the vineyard as is the case with the macroclimate and mesoclimate (Dry & Coombe, 2004).

In large vineyards, spatial variability can also occur, mainly as a result of soil composition and water availability differences within the vineyard itself. The mesoclimate can also influence these differences and they can be expressed even in a vineyard which have the same age, variety and rootstock and which is managed the same all throughout. Precision viticulture services, which used to detect these differences, have been increasing in countries with an advanced wine industry, however, for vineyards smaller than 3 ha, such investment is not feasible because one would not be able to consider selective harvesting within that field (Santesteban, Guillaume, Royo, & Tisseyre, 2013).

2.4.2 Climate change

Grapevines have developed several survival strategies such as a deep root system and efficient stomatal control that allows them to live in a wide range of habitats, however viticulture is strongly dependant on climate (Fraga *et al.*, 2013).The growing season average temperatures in the world's high-quality wine producing regions have increased by 1.26°C from 1950 to 1999 (Jones, White, Cooper, & Storchmann, 2005). The increase in temperature is one of the most significant impacts of climate change since it results in increased transpiration and water consumption, and modifications in the canopy and bunch microclimate (Laget *et al.*, 2008) .

It is extremely important to understand climate change impacts on viticulture as the finest wines have been associated with geographically distinct viticulture regions and the weather and climate of these areas have a direct influence in the production of quality grapes (Jones *et al.*, 2005). The growing season length and temperatures are the main weather and climate factors that affect grape growth and wine quality since they have a major influence on the ability to ripen grapes to optimum levels of sugar, acid, and flavor (Jones *et al.*, 2005). Climate change results in increased sugar content and reduced total acidity of grapes at harvest, and thus this is resulting in earlier harvests (Laget *et al.*, 2008).

The general predicted trend is that in Europe, growing seasons should lengthen and precipitation will increase in the North and decrease in the South (Jones *et al.*, 2005). Spatial modeling showed that there will be geographical shifts of viticultural regions with parts of southern Europe becoming too hot to produce high-quality wines, while northern regions might be more adapted for viticulture (Kenny & Harrison, 1992), thus the notion of *terroirs* in Europe may be effected (Seguin & de Cortazar, 2005) since some varieties might not be adapted to a particular region anymore. Famous winemaking regions have produced distinct wine due to the specific prevailing environmental characteristics (Fraga *et al.*, 2013). According to the OIV (Resolution OIV/VITI 333/2010), "*Terroir* is a concept which refers to an area in which collective knowledge of the interactions between the identifiable physical and biological environment and applied vitivinicultural practices develops, providing distinctive characteristics for the products originating from this area. *Terroir* includes specific soil, topography, climate, landscape characteristics and biodiversity features." Changes in these characteristics will directly impact vine development and berry composition and therefore the quality of wine produced (Fraga *et al.*, 2013).

Annual precipitation and its seasonality are critical factors in viticulture, especially to avoid water stress during budburst, shoot development and from flowering to berry ripening (Fraga *et al.*, 2013). Fraga *et al*. (2013) suggests that in southern Europe, water scarcity and extreme climate conditions may cause a reduction in yields, higher yield variability and a reduction in areas suitable for crops. Irrigation of vines is becoming increasingly necessary in the Mediterranean region of France (Laget *et al.*, 2008). With higher temperatures, budburst becomes earlier and cane maturation extends to longer periods with the result that the dormancy period becomes shorter (Fraga *et al.*, 2013). Other potential impacts of climate change on grape growing include increase pests and disease pressures due to milder winters, sea level rise and its impact on vineyards in coastal zones, the effect of increased carbon dioxide in the atmosphere (Jones *et al.*, 2005), reduction in grape color and an increase in the volatilization of aroma compounds (Fraga *et al.*, 2013). Modifications of plant functions and vigor due to climate change can lead to inhibition of photosynthesis, inhibition of berry development and ripening, loss of fruit volume, and an increase in alcohol content of wines produced in warm areas due to the increased sugar levels brought about by the loss of water by evapo-transpiration and limited water entering the berry or back flow of water from the berry to the plant (Laget *et al.*, 2008).

Short-term mitigation measures to the effects of climate change in order to optimize production can be achieved through changes in management practices such as irrigation and sunscreens for leaf protection (Fraga *et al.*, 2013). Long-term measures may include varietal and land allocation changes so that the vines are grown in areas which are more suitable for them, such as cooler sites, higher altitudes and coastal areas (Fraga *et al.*, 2013), however these might bring new challenges that need to be considered.

The National Climate Change Adaptation Strategy suggests that "Malta should consider supporting an EU Soil Directive that is risk-based, proportionate, and sufficiently flexible to address national and local circumstance." It also encourages the continuation of the EU Common Agricultural Policy reform so that those activities providing environmental benefits are awarded. The report views the provision of treated sewage effluent to be used in agriculture as a good economic substitute to the use of groundwater, if it is offered at a reasonable price (MRRA, 2012b).

2.5 European Policies and Projects

2.5.1 The Common Agricultural Policy (CAP)

There is a wide variety of farming carried out in Europe, including intensive, conventional, and organic farming. There are about 12 million farmers in Europe with an average farm size of about 15 hectares, a scenario that is much different from the US were there are about 2 million farmers with an average farm size of 180 hectares. With increasing expenses and given the difficulty of the work involves, very few youths are working the land, which results in a present scenario in Europe where 30% of the farmers are over 65 years and only 6% are younger than 35 years. As an incentive to offset this imbalance, a new scheme was published in 2013 which gives a 25% bonus of the amount of direct payments payable to young farmers in their first five years of working in the sector (EC, 2013). The Common Agricultural Policy for the European Union was designed to "support farming that ensures food safety in a context of climate change and promote sustainable and balanced development across all Europe's rural areas, including those where production conditions are difficult." It gives incentives to farmers to meet the needs of the 500 million Europeans. In June 2013 the three main priorities set were: viable food production, sustainable management of natural resources, and balanced development of rural areas throughout the EU (EC, 2013). Direct incentives to farmers are important because only a small part of the price that consumers pay for their products go to farmers, and even though the food prices have increased all over Europe, this still does not compensate for the increased expenses that farmers have to make. While the prices for agricultural products have increased by about 50% on average, the energy bills for farms have increased by 223% and the price of fertilizers by 163% (EC, 2013).

2.5.2 The Integrated Administration and Control System (IACS)

European Union member states give direct financial support to their farmers through the Common Agricultural Policy (CAP). The Integrated Administration and Control System (IACS) is used to ensure that transactions financed by the European Agricultural Guarantee Fund (EAGF) are carried out and executed correctly, and it is also used to prevent and tackle irregularities. Direct aids to farmers account for about €40 billion, which is around 90% of the expenditure financed from the EAGF (EC, 2012). IACS consists of a number of computerized and interconnected databases that are used to receive and process aid applications and respective data. It includes a unique identification system for farmers, an identification system covering all agricultural areas called Land Parcel Identification System (LPIS), an identification system for payment entitlements, and a system for identification and registration of animals (EC, 2012).

2.5.3 BioDiVine

The BioDiVine project, which started in 2011 and runs to 2014, aims to set up conservation actions in seven European vineyards located in France (4 sites), Spain (2 sites) and Portugal (1 site). It involves the study and management of biodiversity in viticultural landscapes with the objective to identify the interest of plot and landscape management in wine regions on biodiversity, landscape and overall environment (Rochard *et al.*, 2011). This project is cofounded by the European initiative LIFE+ 2009/2014 that supports innovative activities related to nature conservation and biodiversity. Biodiversity measures are focused on several taxa of arthropods, plants, soil microorganisms, birds and mammals (Porte, Rochard, van Helden, Guenser, & Fulchin, 2011). Alternative or integrated protection practices are considered, particularly involving the use of predictive models of disease, development of mating disruption by pheromones, and optimization of spraying, while GIS will be used to assess the outcomes obtained from the conservation actions (Rochard *et al.*, 2011). GIS allows for a precise analysis of land cover composition, structure, diversity and the consideration of multiple additional parameters and this makes it ideal to be used as a guide for biodiversity conservation measures. In this project, GIS maps are allowing the landscape manager to discuss several conservation strategies with the farmer and thus ensuring that the ecologic connectivity (with semi-natural habitats) is increased but the farming practices are not disturbed, for example by ensuring that the passage for agricultural machinery remains available (Porte *et al.*, 2011).

2.5.4 ProMed

The project ProMed was set up through collaborations from Italy and Malta to investigate the winegrowing and winemaking practices in minor islands of the Mediterranean with the aim of preserving, protecting and enhancing these minor islands through the development of the vine and its derivatives (ProMed, 2013). The islands involved were Pantelleria, Linosa, Malta and Gozo. New strategies for vineyard management were investigated in order to ensure cost effective management and enhancement of the territories. Studies were carried out in the field to explore the right management techniques for the production of grapes of high quality and vinification trials were done to explore the oenological potential of the two local varieties, however, these studies have not yet been published (Gambin, 2013).

3 Methodology

3.1 Area of study

3.1.1 General overview of the geography of the Maltese Islands

The geology of the islands consists of marine sedimentary rocks, mainly limestone of Oligo-Miocene age and some minor quaternary deposits of terrestrial origin. The five main rock types in order of decreasing age are:

- Lower Coralline Limestone (exposed to a thickness of 140 m). This is the oldest exposed rock type in the Maltese Islands and its formation started about 25-30 million years ago.
- Globigerina Limestone (exposed to a thickness ranging from 23 m to 207 m).
- Blue Clay (exposed to a maximum of 65 m).
- Greensand (exposed to a maximum of 12 m).
- Upper Coralline Limestone (exposed to a maximum of 162 m) (Schembri, 1993).

There are no mountains on any of the islands and both Malta and Gozo are tilted seawards to the northeast. The island of Malta is the largest island of the archipelago with an area of about 245.7 km2 and highest point at 253 m above sea level on Dingli Cliffs. The Great Fault bisects Malta at a NE-SW direction, perpendicular to its long axis (Schembri, 1993). The localities on the island of Malta are shown in Figure 4.

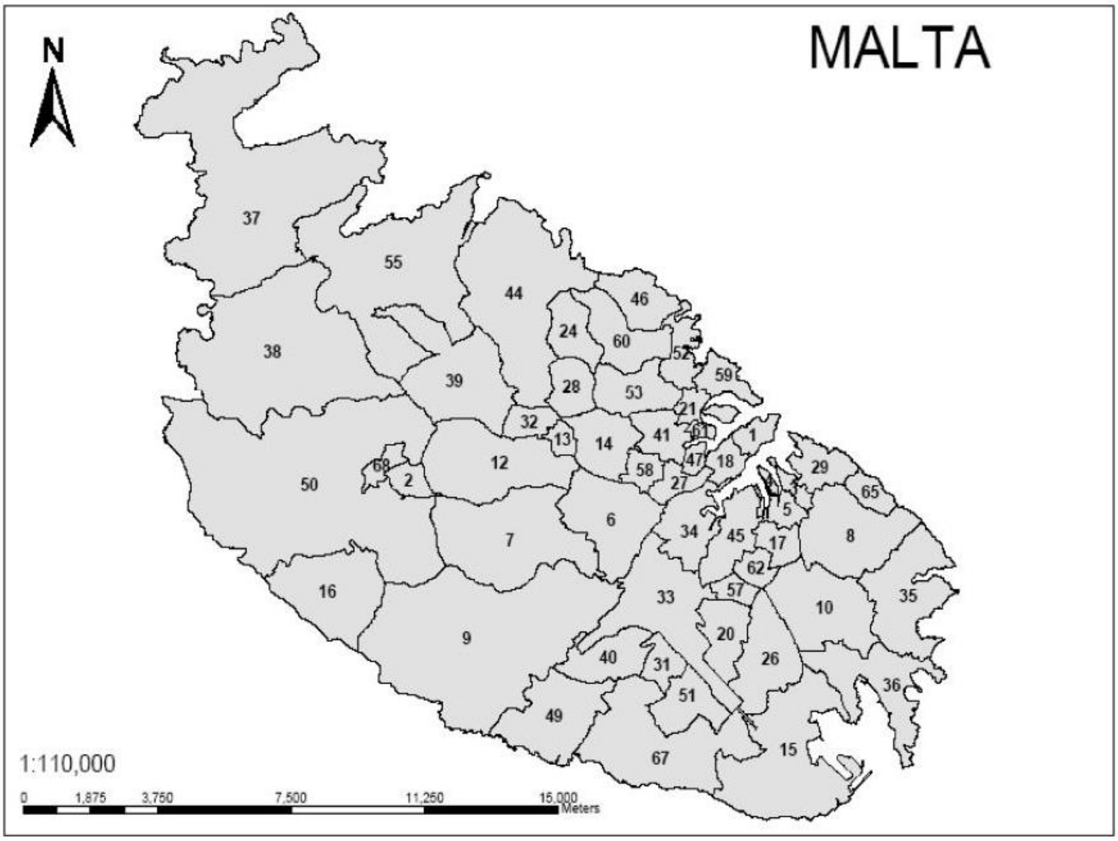

Figure 4 - 1:110,000 scale map of the island of Malta, demarcating the region of grape production falling under the Denomination of Origin "Malta" (LN416, 2007)**.**

Table 4 - The list of localities shown in Figure 4 with their corresponding numbers used for labelling

1 Valletta	24 Għargħur	47 Pietà
2 Mdina	26 Għaxaq	49 Qrendi
3 Birgu	27 Ħamrun	50 Rabat
4 Isla	28 Iklin	51 Safi
5 Bormla	29 Kalkara	52 San Ġiljan
6 Qormi	31 Kirkop	53 San Ġwann
7 Ħaż-Żebbuġ	32 Lija	55 San Pawl il-Baħar
8 Żabbar	33 Luqa	57 Santa Luċija
9 Siġġiewi	34 Marsa	58 Santa Venera
10 Żejtun	35 Marsaskala	59 Sliema
12 Attard	36 Marsaxlokk	60 Swieqi
13 Balzan	37 Mellieħa	61 Ta' Xbiex
14 Birkirkara	38 Mġarr	62 Tarxien
15 Birżebbuġa	39 Mosta	65 Xgħajra
16 Dingli	40 Mqabba	67 Żurrieq
17 Fgura	41 Msida	68 Mtarfa
18 Floriana	44 Naxxar	
20 Gudja	45 Paola	
21 Gżira	46 Pembroke	

3.1.2 Maltese soils

Maltese soils were surveyed between 1957 and 1958 by D.M. Lang in a study which led to a detailed report about the soils of Malta and Gozo and it is still considered as the most detailed study of the soils of the Maltese Islands. Figure 5 shows the map produced by Lang (1960).

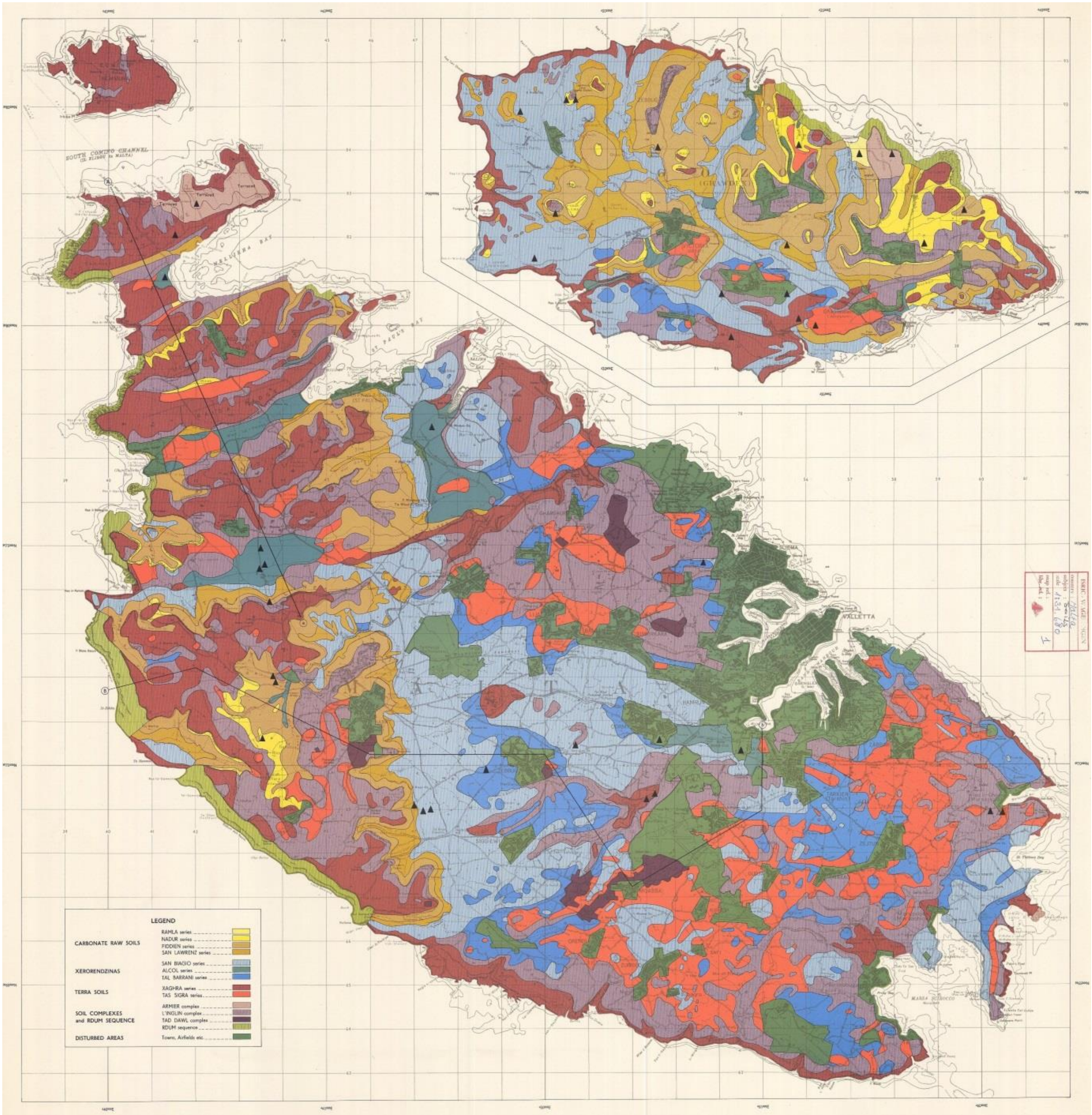

Figure 5 - A map showing the distribution of the soil types as classified by Lang (1960).

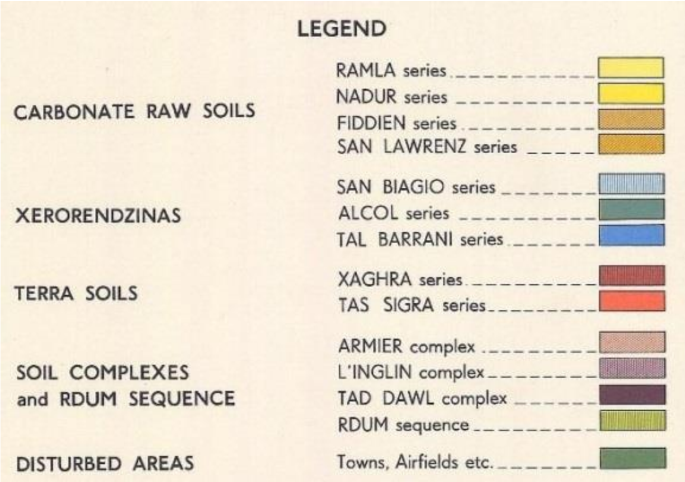

Figure 6 – An enlarged version of the legend in Figure 5 (Lang, 1960)**.**

Using the Kubiena classification system, the Maltese soils can be categorized into three main types:

- Carbonate Raw Soils are immature soils that have a very low organic matter content and very high calcium carbonate content. They develop on weathered quaternary sandstones, Greensand, the lower beds of the Upper Coralline Limestone, Blue Clay and on Globigerina Limestone.
- Xerorendzinas are also immature soils with low organic matter content and contain high calcium carbonate content. They develop on weathered Globigerina Limestone and on valley deposits.
- Terra Soils are the most mature soils that were formed during the Pleistocene and were little affected by the current climatic conditions. They are extensively weathered and have low calcium carbonate and organic matter content. These soils develop on karstland (Schembri, 1993).

A more recent study on Maltese soils was done through the EU funded project MALSIS (Malta Soil Information System) which was coordinated by the Ministry for

Resources and Rural Affairs and finalized in 2004. The data gathered was used in the 'State Of The Environment Report' of 2005 published by the Malta Environment & Planning Authority (MEPA). The MALSIS project classified the Maltese soils into seven categories as follows: calcisols, leptosols, vertisols, luvisols, cambisols, regosols, and arenosols. Calcisols were the most common amounting for 27% of the distribution while arenosols were only found in localized areas and their area of distribution was negligible (MEPA, 2006).

The Maltese soils are mainly characterized by the geological and climatic conditions, however they were also subject to intense human activity such as carting, quarrying, terracing, and the addition of manure (Vella, 2001), which left considerable impact and still is a major concern. They are mostly of shallow depth and vulnerable to soil erosion. Losses of soil are especially common in areas that do not have well managed soil-retaining rubble walls. Another major threat to Maltese soils is soil sealing, that is "the irreversible covering of soil for housing, roads, or other land development, as well as for concreted countryside areas such as livestock farms, certain greenhouses for horticulture, and recreational areas" (MEPA, 2006). Soil contamination can occur through point source contamination but a more widespread contamination is observed through diffused contamination by heavy metals that are present in livestock manures, compost from mixed municipal waste, agricultural chemicals, and treated sewage effluent that are applied to agricultural land (MEPA, 2006).

Soil organic matter is crucial for maintaining soil quality, but intensive cultivation can be one of the reasons causing decline in soil organic matter. Since all Maltese soils contain low organic matter, a threshold of 2% soil organic matter is considered as an environmental indicator, below which probably severe decline in soil quality will occur. In 2006, the average soil organic matter in Malta's topsoil was found to be

2.1%, which is 0.2% higher than it was in 2002. The highest percentage recorded was 4%, in Mellieha, in the far northwest of Malta. Rabat, Mġarr and the adjacent localities all had organic matter in the 1-2% range (National Soils Unit, 2006a). Average soil salinity increased by 30% from 2002 to 2006, with the average recorded in 2006 being 756 µS/cm. The highest values were obtained from coastal zones, including Mġarr (1,580 µS/cm), due to the deposit of sea spray (National Soils Unit, 2006b). The accumulation of sodium in the soil is prevented by the exchange complex that forms due to the high amount of calcium carbonate that is naturally present in Maltese soils (Vella, 2001).

3.1.3 Weather data

As the weather is a very important factor in vineyard management, data regarding temperature, precipitation and wind speed of three viticultural seasons (2009-10, 2010-11, 2011-12) was obtained from the Meteorological Office (MetOffice) of the Malta International Airport in a set of spreadsheet documents. The data provided included the average daily air temperature, the sum of daily precipitation and the daily average wind speed for the period between 1st October 2009 to 30th September 2012. The data for a few days were missing but when considering the size of the dataset, these were negligible and the data could still be used for the purpose of this project. The data for the 29th February 2012 was not used since it was the only leap year in the data set and so the data for that day could not be compared to other years.

3.1.4 Ground water

The fresh water resource in the Maltese Islands depend entirely on rainwater percolating through the porous limestone rock and accumulating in aquifers from where it either seeps out or is pumped by man using boreholes. The largest aquifer is the Mean Sea-level Aquifer that consists of a lens of freshwater which floats on the denser saline water in limestone rock at sea level. The other type of aquifer forms when rainwater in trapped in the permeable Upper Coralline Limestone over the impermeable Blue Clay and this forms the Perched Aquifers (Schembri, 1993).

3.2 Interviews with local growers

One set of interviews was carried out with local growers of the two grape varieties in July and August 2013. A list of local growers that supply the grapes to a local winemaking company was obtained along with contact numbers of the growers, the variety that they grow, the location of vineyard, the yields obtained in the past 3 years and the respective brix (sugar content level in the grapes) for each year. The local company that provided these details was Emmanuel Delicata Winemaker Ltd. These were obtained in spread sheet files which were stored using password protection.

3.2.1 Recruitment

Using the spread sheet software, growers were categorized by location, in a way to ensure that the interviewees are selected from different locations, in proportion to the number of growers and proportion of vineyards in that locality.

For these interviews, growers that had a total vineyard area for that particular variety smaller than 0.1 ha (1000m^2, 0.89 tumoli) were not considered in the recruitment process. The growers were categorized by location as follows:

Table 5 - Showing the localities, area of vineyards and number of growers chosen for each variety for interview

Variety	Locality	Total area of vineyards in recruitment list (ha)	Total area of vineyards in recruitment list (tumuli)	Number of growers eligible for selection	Growers randomly selected for interview
Girgentina	Mġarr	10.738	95.53	26	5
Girgentina	Rabat	8.690	77.31	23	4
Girgentina	Other localities	11.177	99.44	34	6
Ġellewża	Mġarr	6.022	53.58	20	6
Ġellewża	Rabat	3.591	31.95	14	3
Ġellewża	Other localities	8.664	77.08	18	6

A total of 30 growers were interviewed, 15 for each variety. Research participants were contacted by phone prior to the interview and were asked about their willingness to participate in the research project using the telephone recruitment transcript found in the appendix. An appointment was made with the growers that were potentially willing to participate and the investigator visited their vineyard.

3.2.2 The visit

When visiting the vineyard, the investigator introduced himself, explained the study, and provided a written copy of the consent form. In the case that a participant was illiterate, the consent form was read out. In the case that the grower agreed to participate, two copies of the consent form were signed by both the participant and the investigator so that each one kept a copy, and the interview took place. The participants were assured that their replies were confidential and that the storage of all data collected was done under strict protocols to ensure that their identity and the information they provide remain undisclosed. The consent form and the interview questions can be found in the appendix.

The investigator created an identity log sheet in which the name of the grower was assigned a unique number, which was used as an identification code. This was used so that the name of the grower was not written down on the sheet used to write the answers for the interview questions, to ensure that the grower's confidentiality is protected. The identification codes were used to construct a database that aligns interview responses with other data collected about the vineyard, and once the data set was compiled and checked for accuracy, the identification codes were deleted from the dataset. The log sheet and the hard copies of the consent forms were stored in a locked cabinet in the thesis advisor’s office at the University of Malta. The interview notes were stored in a separate locked cabinet in the same office.

The total number of vines for the variety for which the grower was being interviewed was collected by counting the vines and using approximations in the case of relatively large vineyards.

In the case where the grower irrigated the vineyard, three water sample replicates were collected from the water source used for irrigation. The growers were not promised any financial incentive and it was made clear that there were no personal benefits for participating; however the results of the water tests from the water source used for irrigation were made available to the respective grower upon request.

A Garmin GPSMAP® 78s was used to obtain the altitude of the vineyards visited, by using the barometric altimeter function. The instrument was left for one minute to get a reading and then the value was rounded up to the nearest 10 ft.

All communication (recruitment telephone conversation, consent form, and the interview questions) were translated in Maltese to ensure that the growers understood all the information provided.

3.3 Irrigation Water Tests

Water samples from growers who irrigated their vines were collected in 50mL sterile plastic containers and were stored in a freezer at -18°C after the visit to ensure that no chemical changes occurred until the samples were analyzed. During the analysis period, which was of about two weeks, they were kept at 4°C.

3.3.1 Test for water conductivity

The frozen irrigation water samples were placed in a water bath set at 20°C for about an hour to defrost. The samples were then analyzed for conductivity using a Thermo Scientific Orion 4-Star pH/conductivity benchtop meter which had a range of 0.000 to 3000 mS/cm, a resolution of 4 significant digits down to 0.001 µS/cm, and a relative accuracy of 0.5% ± 1 digit or 0.01 µS/cm, whichever is greater.

3.3.2 Test for chlorides

The refrigerated irrigation water samples were placed in a water bath set at 20°C. The concentration of chloride ions was then determined using a Jenco 6230N electropotential meter connected to a computer with ArrowON ION Sampler software. It had a display range of -1999 mV to +1999 mV, an accuracy of ± 0.1%, ±1 digit, and a resolution of 1.0 mV. The instrument was calibrated to 70 mV for the 10ppm standard chloride concentration and at 15 mV for the 100ppm standard chloride concentration.

For both the water conductivity and the chlorides tests, the samples were first agitated to ensure a homogenous mixture and then the probe was inserted in the sample and left for 30 seconds to acclimatize before the reading was taken. The process was repeated for each of the samples collected. The probe was rinsed with distilled water before inserted in any of the samples.

3.3.3 Test for nitrate

The refrigerated irrigation water samples were placed in a water bath set at 20°C. The samples were then analyzed for nitrate (NO_3^-) using a Spectrum Technologies Cardy Nitrate Meter (Item #2300) which had a display range of 0-99 × 100 ppm with the following resolution:

- 1 ppm for 0-99 ppm
- 10 ppm for 10-99 × 10 ppm
- 100 ppm for 10-99 × 100 ppm

The samples were first agitated to ensure a homogenous mixture and then three drops from the sample were gently dropped on the sensor using a pipette. It was left for 30 seconds to acclimatize before the reading was taken. This process was repeated for each of the samples collected. The sensor was rinsed with distilled water and blotted with a soft paper towel as instructed in the equipment manual before the sample was placed on the sensor.

For all three tests, the readings were recorded in a table and the average of the replicate samples were calculated, which was rounded up to a figure that is in line with the equipment's accuracy.

3.4 Data from the Permanent Crops Unit

The data provided by the Permanent Crops Unit within the Directorate for Agriculture gave the areas of field parcels of all the Ġellewża and Girgentina found on the island of Malta. Data for Gozo were also provided but they were not reliable due to technical problems with the vineyard register at the aforementioned Unit, and therefore only the data from the island of Malta were used. The area was quoted in tumoli as it was automatically calculated by the Integrated Administration and Control System (IACS) of the Paying Agency (Gambin, 2013). The size of vineyards in Malta is mostly quoted in tumoli, where 1 tumolo is $1124m^2$. All the measurements of vineyard size used in this project were converted to hectares as it is more widely used in the viticulture industry, especially in Europe. Since a hectare is $10{,}000m^2$, the conversion from tumoli to hectares was achieved by multiplying by a conversion factor of 0.1124.

3.5 Analysis of yield and brix

The yield, brix and date of harvest for 2010, 2011 and 2012 were tabulated using the harvest data provided from Emmanuel Delicata Winemaker Ltd. for each of the two varieties. The yield was taken as the total number of grapes supplied to the winemaking company, while the brix and the date of harvest were from the first collection of grapes, that is, if a grower supplied grapes in more than one day, the total number of grapes was considered, but the sugar level reading was taken from the first day in which the grapes were supplied. This was done because the growers were expected to supply the grapes in one day, but were allowed to take any additional grapes that they did not manage to harvest in subsequent days.

Yield was calculated using the units of tonnes per hectare, as the yield data available was the weight of the grapes harvested. Literature usually quote yield values in hectolitres per hectare, however, there is no single conversion that can be used to calculate the amount of hectolitres of wine produced from a tonne of grapes, as this depends on the press system used and the juice content by weight in the bunches, which varies in different varieties. Some claim that 6.3 tonnes of grapes produce 32.7 hectolitres of wine, meaning a conversion factor from tonnes to hectolitres of 5.19 (Oplanic, Radinovic, & Radinovic, 2010), while others claim that 58 tonnes of grapes from grape varieties such as Cabernet Sauvignon, Chardonnay, Grenache, Merlot, Barbera, and Zinfandel correspond to 329 hectolitres of wine, meaning a conversion factor of 5.67 (Bokulich, Ohta, Richardson, & Mills, 2013). With Ġellewża and Girgentina both consisting of large berry size, the conversion factor should be even higher than that. According to the Green Paper on Maltese quality wines, in Malta 7282 hectolitres of DOK wines and 6640 hectolitres of IĠT wines were produced from a total of 1981 tonnes of grapes of different varieties (MRRA, 2012a), which gives a conversion factor of 7.02.

Correlations between brix and yield for different seasons for both varieties was done using Pearson correlations tests in order to find the degree of linear dependence between the two variables. Comparisons of brix and yield for different seasons and between the two varieties were performed using a number of two-tailed t-tests. Principal Component Analysis (PCA) was then used to identify trends when multiple factors are considered, such as the effect of the location on brix and yield and the effect of different water components on brix and yield. The brix and yield of irrigated and non-irrigated vineyards was also investigated using PCA.

4 Results and Analysis

4.1 Vineyard parcels and locations

Every parcel containing any one of the two main indigenous grape varieties is registered with the Permanent Crops Unit of the Agriculture Directorate along with the locality at which it is found and the size of the parcel. From the list of parcel sizes that was provided, the data were organized in two tables, one for each variety, and the number of parcels, average size, standard deviation, and total size for each locality was analyzed. The percentage of the total size for each was then calculated from the total size of all localities. Table 6 and Table 7 show the list of all parcels of Girgentina and Ġellewża in Malta, including those grown for personal consumption as table grapes or used to produce homemade wine.

Table 6 - The list of parcels of Girgentina in Malta classified by locality

Girgentina		Hectares			Percentage (%)
Locality	**No of parcels**	**Average size**	**Std Dev**	**Total size**	**Total size**
Mġarr	504	0.118	0.092	59.237	33.145
Rabat	341	0.119	0.092	40.475	22.647
Żebbuġ	42	0.638	2.479	26.810	15.001
St. Paul's Bay	96	0.132	0.093	12.677	7.093
Siġġiewi	101	0.106	0.106	10.678	5.975
Attard	32	0.164	0.090	5.239	2.931
Mosta	38	0.135	0.134	5.112	2.860
Mellieħa	53	0.077	0.070	4.106	2.297
Mdina	19	0.149	0.079	2.839	1.589
Dingli	30	0.078	0.051	2.343	1.311
Burmarrad	5	0.439	0.338	2.193	1.227
Naxxar	21	0.094	0.078	1.979	1.107
Zurrieq	24	0.038	0.047	0.906	0.507
Birżebbuġa	17	0.038	0.032	0.645	0.361
Safi	14	0.044	0.038	0.612	0.342
Qrendi	15	0.039	0.027	0.586	0.328
Mtarfa	6	0.084	0.062	0.506	0.283
Iklin	10	0.025	0.011	0.254	0.142
Zejtun	4	0.061	0.039	0.243	0.136
Zabbar	6	0.036	0.024	0.215	0.120
Gudja	2	0.087	0.050	0.174	0.097
Luqa	7	0.024	0.019	0.171	0.096
Mqabba	6	0.028	0.018	0.166	0.093
Marsa	1	0.132	0.000	0.132	0.074
Qormi	3	0.043	0.036	0.130	0.073
Marsaxlokk	1	0.120	0.000	0.120	0.067
Ghaxaq	3	0.028	0.015	0.085	0.048
Gharghur	3	0.021	0.016	0.063	0.035
Lija	9	0.003	0.006	0.024	0.013
Total	**1413**	**0.126**	**0.442**	**178.721**	**100**

Table 7 - The list of parcels of Ġellewża in Malta classified by locality

Ġellewża		**Hectares**			**Percentage (%)**
Locality	**No of parcels**	**Average size**	**Std Dev**	**Total size**	**Total size**
Mġarr	288	0.097	0.073	27.965	34.588
Rabat	174	0.127	0.291	22.040	27.260
St. Paul's Bay	89	0.137	0.101	12.164	15.045
Naxxar	28	0.160	0.129	4.446	5.499
Mosta	27	0.119	0.065	3.203	3.962
Siġġiewi	34	0.057	0.043	1.950	2.412
Mellieha	31	0.059	0.045	1.830	2.263
Attard	12	0.100	0.138	1.206	1.492
Dingli	18	0.055	0.049	0.986	1.220
Żebbuġ	19	0.042	0.035	0.790	0.977
Burmarrad	4	0.172	0.141	0.687	0.850
Mdina	8	0.080	0.104	0.636	0.787
Zejtun	11	0.041	0.039	0.455	0.563
Kirkop	1	0.367	0.000	0.367	0.454
Luqa	6	0.051	0.027	0.303	0.375
Mtarfa	2	0.127	0.020	0.254	0.314
Qrendi	6	0.041	0.040	0.248	0.307
Qormi	6	0.038	0.026	0.229	0.283
Zabbar	5	0.035	0.028	0.177	0.219
Iklin	2	0.087	0.077	0.174	0.215
Safi	4	0.039	0.027	0.155	0.192
Marsa	1	0.124	0.000	0.124	0.153
Zurrieq	6	0.018	0.016	0.107	0.132
Ghaxaq	3	0.034	0.027	0.102	0.126
Gharghur	2	0.037	0.035	0.074	0.092
Mqabba	2	0.031	0.002	0.062	0.077
Marsaxlokk	2	0.023	0.009	0.046	0.057
Birżebbuġa	1	0.028	0.000	0.028	0.035
Lija	8	0.003	0.006	0.024	0.030
Total	**800**	**0.101**	**0.155**	**80.852**	**100**

There are 1413 parcels registered for Girgentina and 800 parcels for Ġellewża. This shows that historically local growers preferred to grow Girgentina over Ġellewża, in fact, the area of land covered with Girgentina is more than twice that of Ġellewża. A definite explanation for why Girgentina is more common was not found, however, possible reasons could be that the locals preferred drinking white wine and the taste of the Girgentina grapes, or that the availability and grafting process for Girgentina was easier. The average parcel size is just above 0.1ha, which shows that most of the parcels are very small. This is a very important consideration that needs to be kept in perspective when analyzing the management of these varieties. Even in cases where a farmer owns various parcels, since the parcels are small it is very difficult to have any mechanization that would allow the management of large areas which can bring considerable profit. On the contrary, most parcels are small, some are only managed for personal consumption and most of the work done requires a lot of manual labor. This brings an opportunity for the farmers to choose sustainable management practices that are easier to implement on small areas, such as cultivation without the use of tractors that compact the soil, inspecting the vineyard regularly for any diseases present, and spraying with hand held devices using an integrated pest management system. The small vineyards also allow for the traditional hand picking of grapes.

For Girgentina, Mġarr and Rabat together amount for more than 55% of the area occupied by this variety when compared to other localities, while for Ġellewża these two localities amount for more than 60% of the total area occupied. Other localities that have a notable amount of indigenous vines include Żebbuġ, St. Paul's Bay, Naxxar, Mosta, and Siġġiewi, which are all located close to Mġarr and Rabat. This means that nearly all the Ġellewża and Girgentina in Malta are found on the Western side of the island.

4.2 The Weather

Weather conditions can have a direct effect on grape production and quality. The weather data investigated in this project consisted of temperature, precipitation, and wind speed and consisted of daily values for each for a three year period from 1st October 2009 to 30th September 2012, which corresponds to the three seasons under investigation for yield and other harvest data.

4.2.1 Temperature

The climate of the Maltese Islands is Mediterranean, sometimes referred to as a semi-arid climate; consisting of mild, wet winters and hot, dry summers. Air temperatures are moderate and relative humidity is constantly high throughout the year at a range of about 65-80%. The Maltese Islands are well known for their long hours of sunshine and for the period 1951-1990 they received an average of 8.3 hours of bright sunshine daily (Schembri, 1993). The temperature data for the three year period were relatively similar from one year to another and showed the typical Mediterranean climate characteristics. The data are presented in Figure 7:

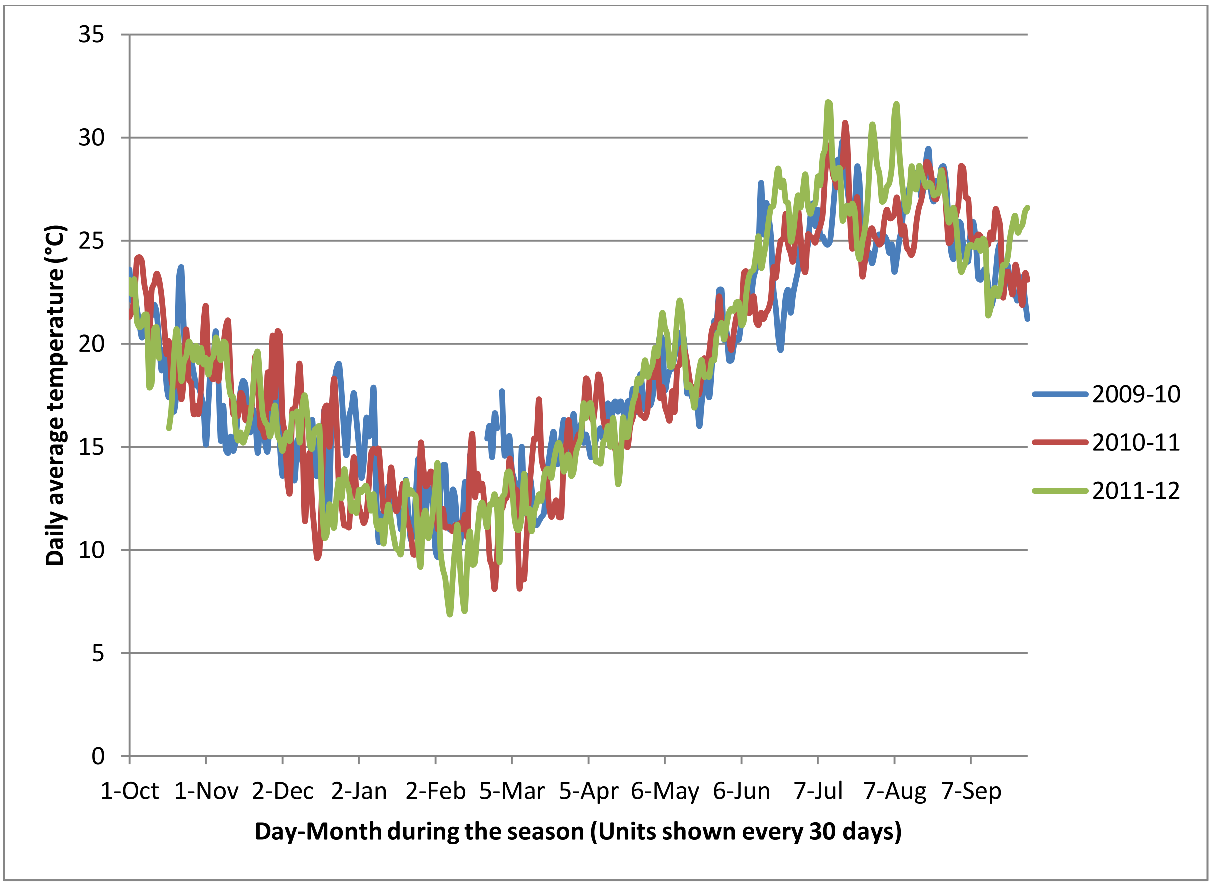

Figure 7 - Daily average temperature (°C) throughout the season for three seasons

The season 2011-12 had the lowest and highest temperatures with a daily average of 6.9°C and 7.1°C in 8th and 14th February respectively and 31.7°C and 31.6°C in 11th July and 8th August respectively. The coldest days on the 2010-11 season occurred a bit later than for in 2011-12 while the 2009-10 season did not have particularly cold weather. The cold weather in winter is important for the vines to rest and prepare for the new season. As the temperature starts increasing again, bud break is induced and the new growth emerges.

4.2.2 Precipitation

Rainfall in the Maltese Islands is highly variable from year to year but the average annual precipitation for the period 1951-1990 was 530 mm. The wet period is from October to March and receives around 85% of the total annual rainfall (Schembri, 1993). The precipitation values obtained for the three seasons under study are summarized in Table 8:

Table 8 - Precipitation values in mm and % for three seasons, categorized in three different parts

	2009-10		2010-11		2011-12	
	mm	**%**	**mm**	**%**	**mm**	**%**
Oct-Mar	218.5	70.4	463.7	92.0	421.2	80.1
April-July	17.5	5.6	30.9	6.1	27.1	5.2
August-Sept	74.5	24.0	9.4	1.9	77.8	14.8
Total	**310.5**	**100**	**504.0**	**100**	**526.1**	**100**

Table 8 divides the precipitation in three groups which reflect different periods of the viticultural season. The first group is between October and March which is the period that starts after harvest and includes the dormancy period until bud burst. Here water is important so that the soil retains as much moisture as possible for the growing period. The second group is in fact the growing period in which the new canes emerge and includes flowering and fruit set. In this case water is also very important for good vine growth but the data show that only about 5-6% of the precipitation falls within this period, hence the vine needs to rely on the water stored in the soil during the previous months and on additional water through irrigation if this is available, especially in July when the heat stress increases. The final group includes August and September which is the period in which the grapes mature and harvest occurs. Here water is needed to avoid heat stress but rainfall can lead to damage to the grapes and induce mold to grow.

The data in the table show that there was an increase in the total precipitation from one season to another. The 2009-10 season had a very low annual precipitation which definitely results in more stress to the vines. While the 2010-11 season had a slightly lower annual precipitation than 2011-12, the precipitation until march and until July was actually higher, since nearly 15% of the precipitation in 2011-12 season occurred at the end of the season.

A detailed description of the daily precipitation for these three seasons is presented in Figure 8:

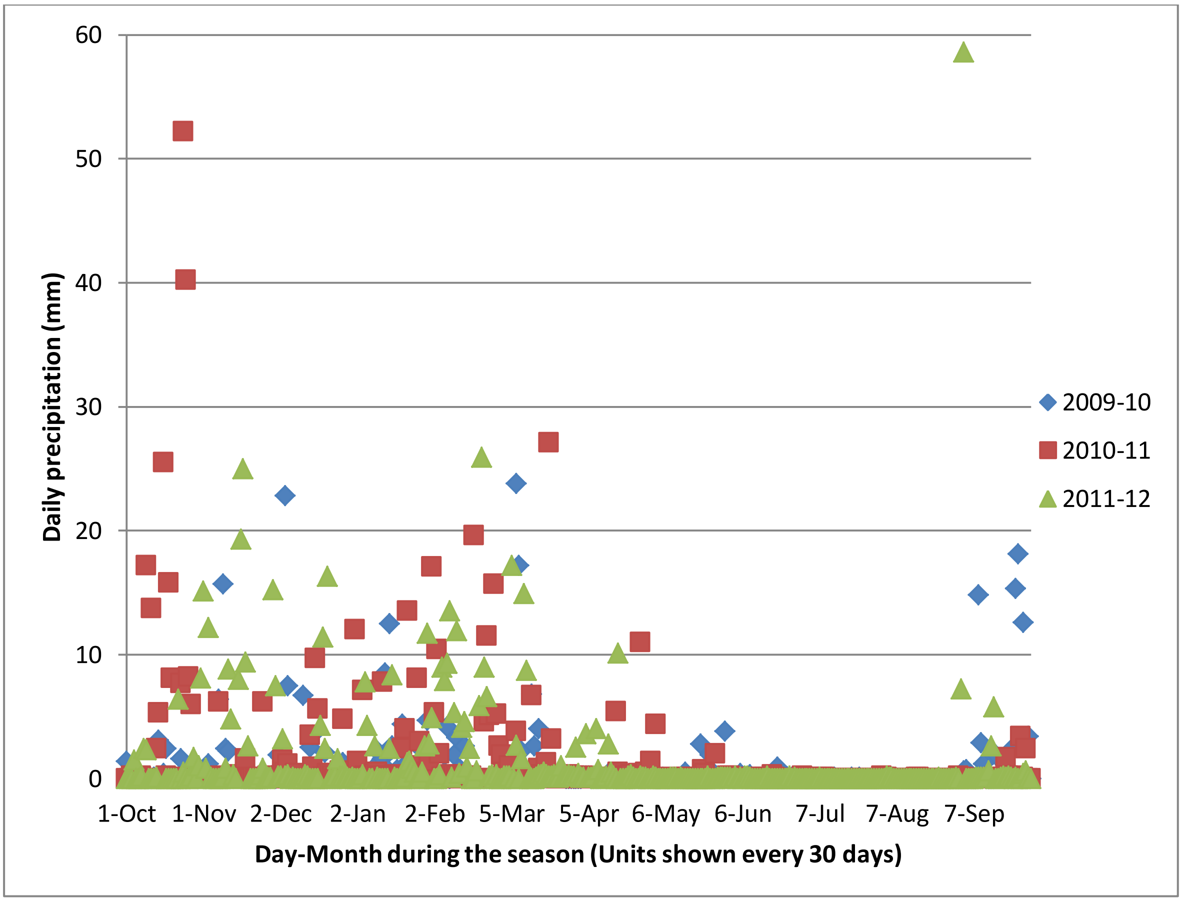

Figure 8 - Daily precipitation (mm) throughout the season for three seasons

Figure 8 shows that the 2010-11 season (represented by red squares) had various heavy rainfalls in October, while the 2011-12 season (represented by green triangles) had a day of heavy precipitation on 3rd September 2012 in which 58.6 mm of rain was recorded. The 2009-10 season (represented by blue diamonds) did not have any days with rainfall exceeding 25mm and this is probably one of the reasons why the annual precipitation of that season was low.

A large amount of rainfall can be beneficial in soils with high salinity as it will flush the salinity away, however huge quantities of rainfall in a very short period can lead to soil erosion, especially when they happen after months of dry weather. Another issue related to rain in September is due to the fact that harvest of Ġellewża and Girgentina usually occurs in mid-September and therefore any rain before harvest can create various other problems, such as limits the access to vineyards which are on slopes or in areas with clay and damages the grape bunches that are close or on the soil in bush vines.

4.2.3 Wind speed

The Maltese Islands are windy and only about 8% of the days are considered to be calm. The northwesterly wind is predominant and blows on 19% of windy days while the other winds are nearly equally represented (Schembri, 1993). Considering that the majority of the indigenous grape varieties are located in the northwestern part of the island, many fields can be quite exposed to wind and therefore this needs to be given an important consideration when analyzing management practices. Since wind can be variable throughout the year, it was particularly important to present the daily wind speed for the period under study, and this can be observed in Figure 9:

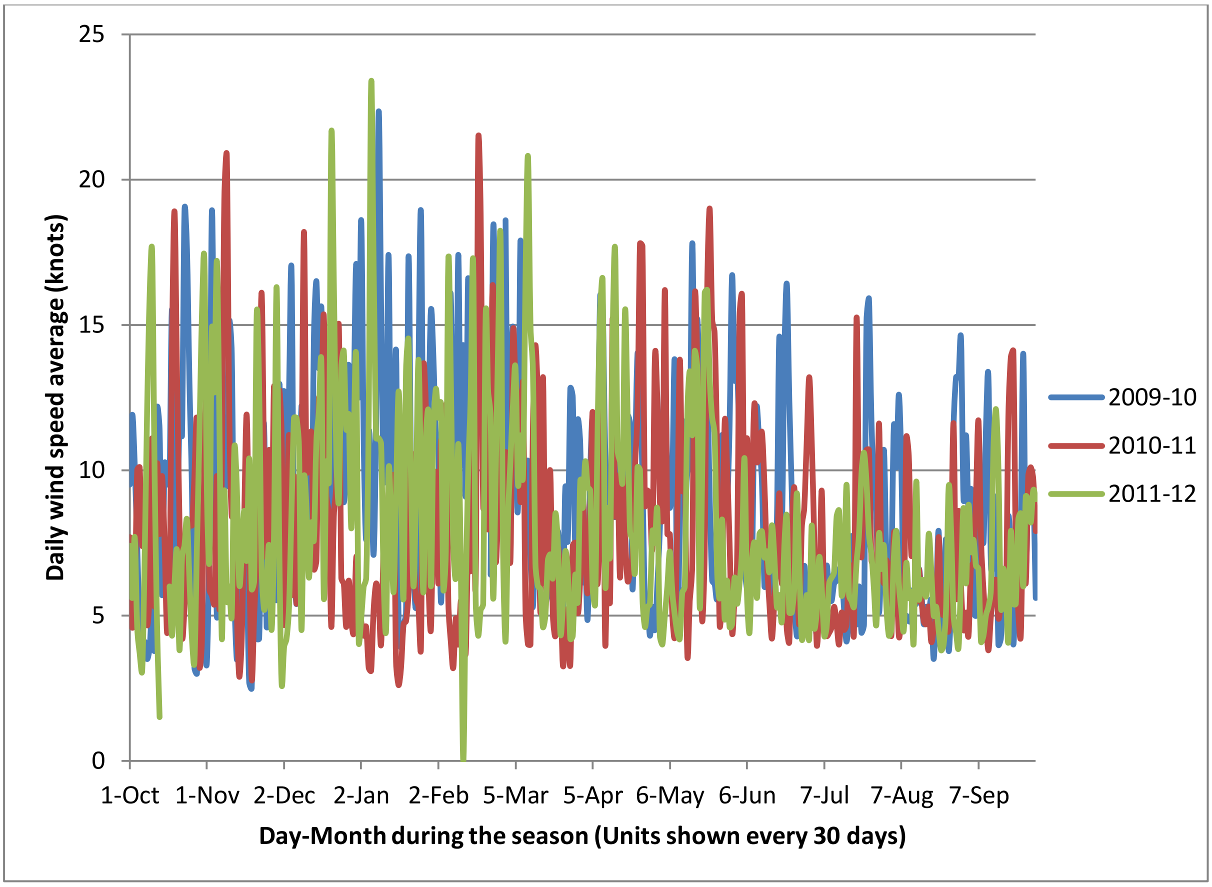

Figure 9 - Daily wind speed average (knots) throughout the season for three seasons

One knot corresponds to 1.852 km/hr. The average wind speeds recorded were 9.2 ± 3.8 knots for 2009-10, 8.1 ± 3.6 knots for 2010-11, and 8.2 ± 3.6 knots for 2011-12. However the highest wind speed was recorded on 6th January 2012 at 23.3 knots. Wind speed for vines is particularly important from bud break to the period of veraison because it is during that time that the new growth is fragile and susceptible to wind damage and it is also the period when the grower needs to find days with low wind so that spray applications can be made. For this reason, the data from 1st March to 31st July are presented in a separate figure to be shown in with a better resolution:

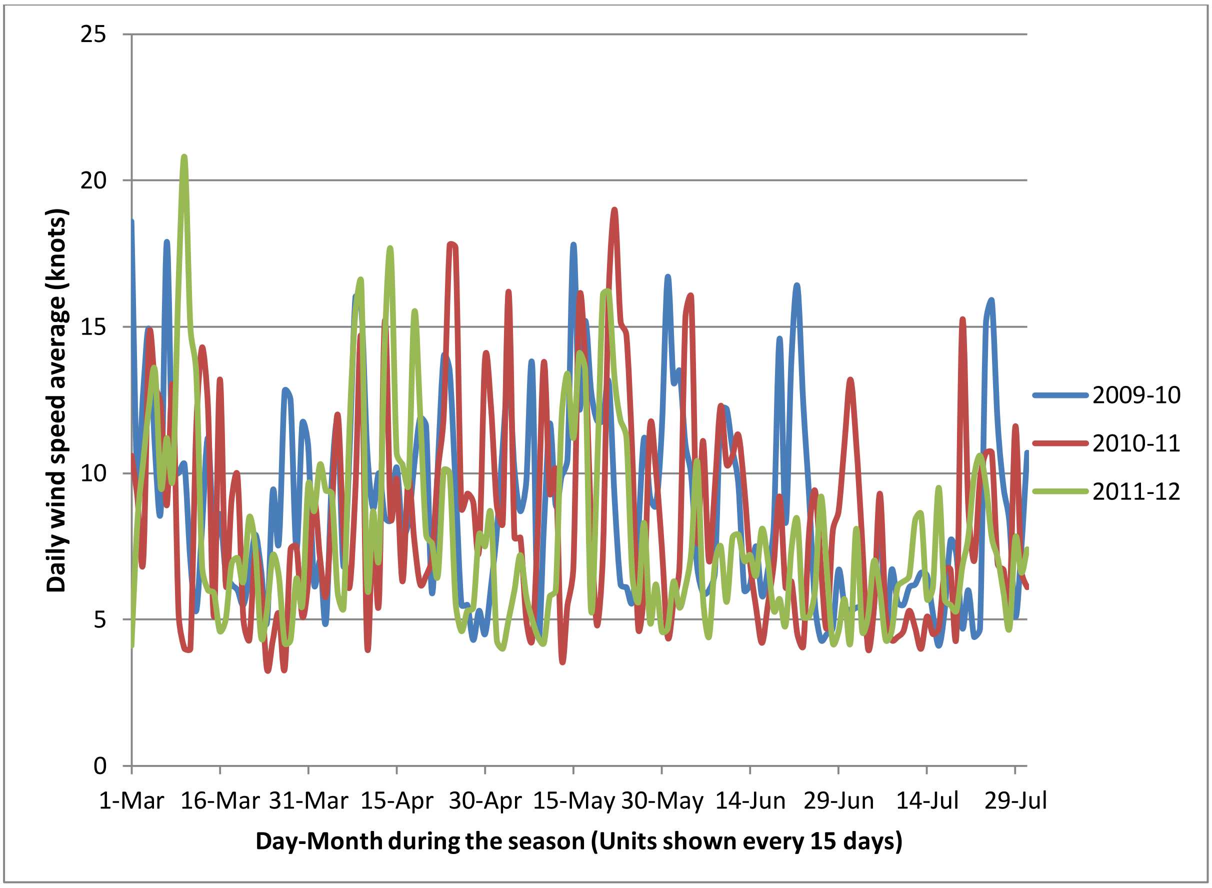

Figure 10 - Daily wind speed average (knots) between 1st March and 31st July for three seasons

Pesticide sprays are mostly done using a knapsack sprayer due to the small size of the parcels and since most vines are pruned as bushes. Such spraying technique allows the nozzle to be directly aimed at the plant and is less affected by wind speeds than techniques such as the use of tractors or aerial spray methods. However, spraying in strong winds should always be avoided as this will not only lead to the waste of the plant protection product and undesired effects on the nearby environment but can also put the grower's safety at risk. Predicting wind speed is not easy and the grower will have to wait for the right weather conditions, however since this can be usually done by one person it is not a major issue, unless the pesticide sprayer is not the grower himself and is booked to come at a particular day which might not have the ideal conditions. Malta's National Action Plan for Sustainable Use of Pesticides 2013 – 2018 does recommend that spraying should not be done in strong wind speeds or very high temperatures (MCCAA, 2013), but it does not give any values to indicate what is considered as a strong wind speed. According to the Beaufort scale, wind speeds up to 10 knots are considered as a gentle breeze, which would probably be good for spraying, however one should note that the data presented above show the daily average and therefore higher wind speeds can be expected during the day.

4.3 Yield and sugar levels

The yield and the sugar levels are considered among the most important factors in viticulture and are the two main two criteria used in the QWPSR classification system in Malta to determine whether the harvest from a parcel can be considered as of DOK, IĠT, or table wine standard. Yield is definitely of importance for the growers as they obtain more profit if they have higher yields and the sugar content is important to ensure that the price they get is of the highest standard possible. These two criteria were analyzed separately for each of the two indigenous varieties because each variety can have its characteristics.

4.3.1 Correlation between yield and brix using harvest data

A Pearson correlation test was run on the harvest data for each of the three years under investigation for each variety to investigate if there is a correlation between the yield and the sugar levels (brix). For Ġellewża, there was no significant correlation observed between these two factors for 2010 ($p=0.955$) and for 2012 ($p=0.389$), however a significant correlation was observed for 2011 ($p=0.028$). For Girgentina, no significant correlation was found between yield and brix in any of the three years with p-values of 0.093 for 2010, 0.507 for 2011, and 0.395 for 2012. Using the harvest data for these three years one can conclude that is not usual for yield and brix to be in correlation with each other for these two varieties. However, one needs to keep in mind that the data supplied was from growers who performed their usual practices without trying to affect the yield to improve the brix, such as by cluster thinning. Studies show that contrary to what wine enthusiasts usually report, reducing the yield of vines does not necessarily result in an increase in the quality of the wine and therefore any reduction in the number of grapes will only be contributing to loss of profit for the grower. Research carried out on Riesling in New York showed that cluster thinning had little or negligible effects on berry size, pH, titratable acidity, pruning weight, cluster light exposure, and bud cold hardiness. Cluster thinning did however enhance fruit ripening and increased the sugar levels (Preszler, Schmit, & Heuvel, 2013).

4.3.2 Seasonal changes in brix and yield

A comparison of the brix and the yield over different seasons was performed through a series of two-tailed t-tests to determine whether the changes in yield and brix levels along the years are significantly different. The data used for this analysis is only using growers who had sold their grapes to the winemaking company in all the three years to ensure that the same list of growers is used in each year. For Ġellewża, brix levels were not found significantly different as the following p-values were obtained:

Table 9 - P-values obtained from two-tailed t-tests on brix levels for different harvests of Ġellewża

Harvest years under investigation		p-value
2010	2011	0.099
2010	2012	0.066
2011	2012	0.681

Since all p-values obtained were greater than the significance level of 0.05, one cannot reject the null hypothesis stating that the difference between the means is equal to 0. The average brix levels obtained were 19.9 for 2010, 19.2 for 2011, and 19.0 for 2012.

For Girgentina, some significant differences in the brix levels were observed in the same seasons under investigation, as shown in Table 10:

Table 10 - P-values obtained from two-tailed t-tests on brix levels for different harvests of Girgentina

Harvest years under investigation		p-value
2010	2011	< 0.0001
2010	2012	0.005
2011	2012	0.138

The average brix levels obtained were 18.4 for 2010, 19.2 for 2011, and 19.9 for 2012. The t-tests therefore confirm that the sugar levels in 2010 were significantly lower than they were 2011 and 2012, and the sugar levels in 2011 and 2012 were not significantly different.

When the yields for Ġellewża were compared, two of the three tests showed that there were significant differences as shown in Table 11:

Table 11 - P-values obtained from two-tailed t-tests on yield values for different harvests of Ġellewża

Harvest years under investigation		p-value
2010	2011	0.737
2010	2012	0.015
2011	2012	0.034

The results indicated that the yield of 2012 was significantly different from the yields of the other two years. In fact, it was significantly higher with an average of 9003 kg/ha for 2012, compared to the 5558 kg/ha for 2010 and 5133 kg/ha for 2011. The weather data observed showing that the 2011-12 season had the lowest winter temperatures, the highest summer temperatures and the highest annual precipitation when compared to the other two seasons could be the reason for such a change in yield. This hypothesis that the weather for 2012 was ideal for a higher yield was confirmed because the same trends were observed when investigating the yields for Girgentina. Table 12 provides the p-values obtained:

Table 12 - P-values obtained from two-tailed t-tests on yield values for different harvests of Girgentina

Harvest years under investigation		p-value
2010	2011	0.675
2010	2012	0.000
2011	2012	< 0.0001

The average yields for Girgentina were 3688 kg/ha for 2010, 3440 kg/ha for 2011, and 6265 kg/ha for 2012.

4.3.3 Varietal differences in brix and yield

Following brix and yield analysis for each variety, the differences in yield and brix between the two indigenous varieties were also investigated to determine if one tackle both varieties in same way when it comes to management practices, policies, and profitability.

The brix levels were only found significantly different for 2010 (p=<0.0001) as the sugar levels for Girgentina were lower in that season, as already discussed. There were no significant differences observed in the brix levels of 2011 (p=0.796) and 2012 (p=0.753).

Meekers (2006) reported that in early September Girgentina used to be harvested first and then Ġellewża sometime after. Throughout the three seasons under investigation, Ġellewża was harvested about a week before Girgentina. Probably since Ġellewża is mostly being used to make rosé wines, winemakers can opt to harvest it earlier, to avoid the damages that can be caused by heavy rain in September. On the other hand, since Girgentina is either used to make single varietal white wines or blended with other varieties that usually have higher sugar levels, it is allowed to ripen for a few weeks more. The data available for this study did not include brix data about the same variety harvested in different weeks and so the change in brix levels for the same variety over time could not be investigated. Since both varieties were found to have similar brix levels and these levels are generally lower than those of international varieties, it is important for a study to be carried out that considers different harvest dates, spaced out over a number of weeks, possibly even until October, and a brix analysis for the same variety and for the same season is carried out to determine whether the brix increases if the harvest is prolonged further than the current period. One should also need to consider that it is very difficult to convince growers to leave the grapes in their fields for more weeks, as this would increase the risk of having heavy storms flooding their vineyards and also increasing the time for diseases and damages to occur.

For all three seasons under investigation, the average yield for Ġellewża was higher than the average yield for Girgentina. Two-tailed t-tests gave values of p=0.038 for 2010, p=0.051 for 2011, and p=0.025 for 2012. This shows that at a significance level of 0.05, the yield for 2010 and 2012 were found significantly different and the yield for 2011 was just on the borderline for being significantly different. Once should note that while the average yield for Ġellewża is higher, since the area planted with Girgentina in Malta is more than double than that of Ġellewża, the total yield in Malta is likely to be higher for Girgentina every year.

4.3.4 Effect of location on brix and yield

The location of vineyards exposes the vines to a combination of characteristics that are only found in that specific place and therefore gives grapes that are of different quality. This concept has been widely observed and is the basis for the protection of the denomination of origin of wines, to ensure that wines made from grapes of a particular region or location, are indeed made only from those grapes. However, given the small size of the island of Malta, it is not clear if the location within the island makes a significant difference in the quality of grapes produced. This study was limited on the brix and yield data and so only these two factors were investigated. A principle component analysis (PCA) using Pearson correlation was carried out on the data available for each variety for growers that sold their grapes to the winemaking company for all three seasons under study so that the brix and yield data for all three seasons was included in one analysis along with the location of the vineyards.

Figure 11 shows the PCA for Ġellewża:

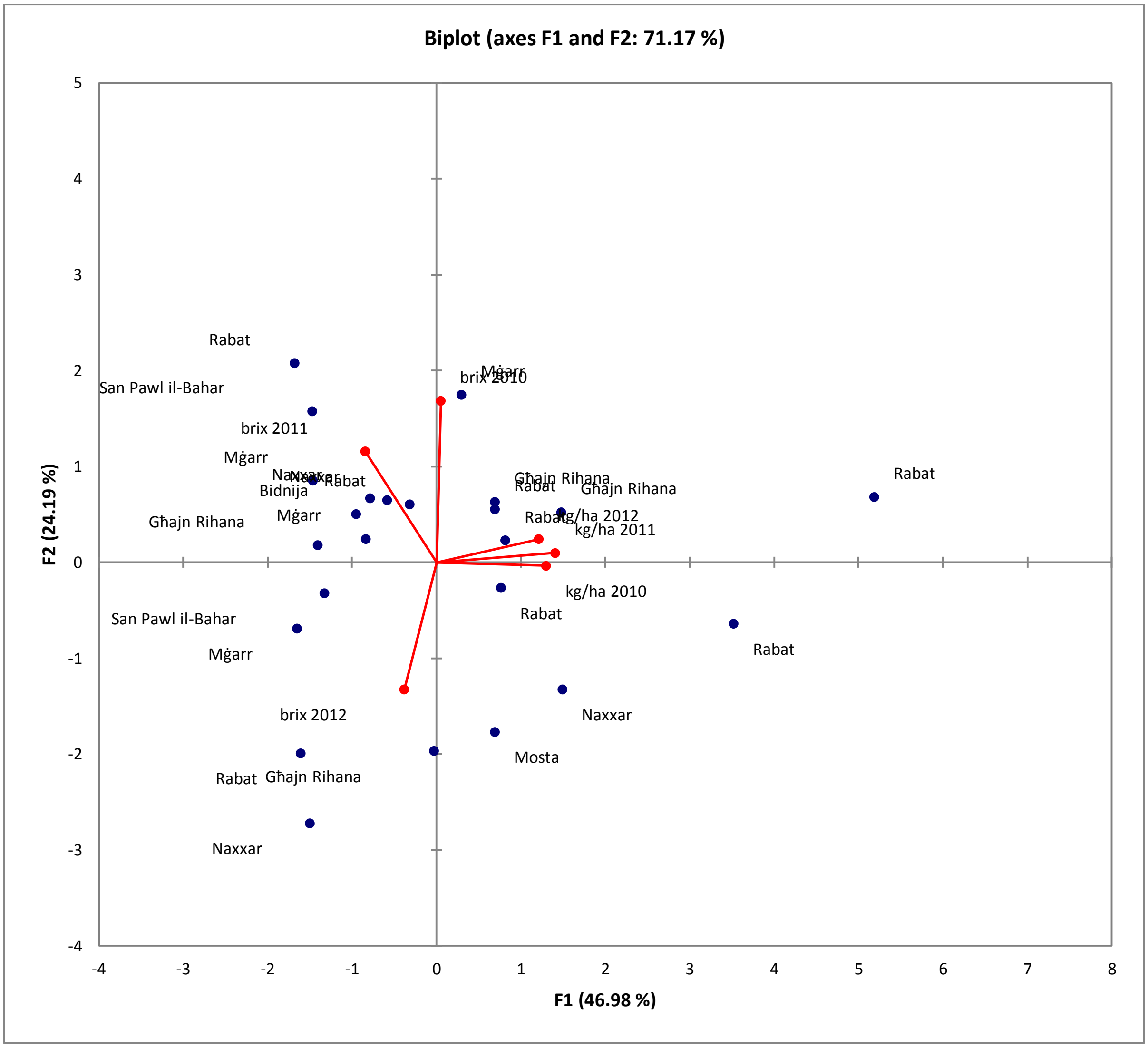

Figure 11 - PCA plot showing Ġellewża parcels labeled by location as affected by brix and yield levels of different seasons

The three brix variables are shown pointing to different directions, while the yield variables are all pointing towards the right. The locations are spaced quite randomly and no general trends are observed. If one location had more yield than others all the growers for that location would have been found on the right hand side. Rabat is seen to give the best yields for Ġellewża, but this cannot be stated for all the vineyards in Rabat. Since the brix variables are not even similar for each season, one can conclude that there is no particular trend with regards to the brix and the corresponding location.

A similar analysis was carried out for the Girgentina vineyards as shown in Figure 12:

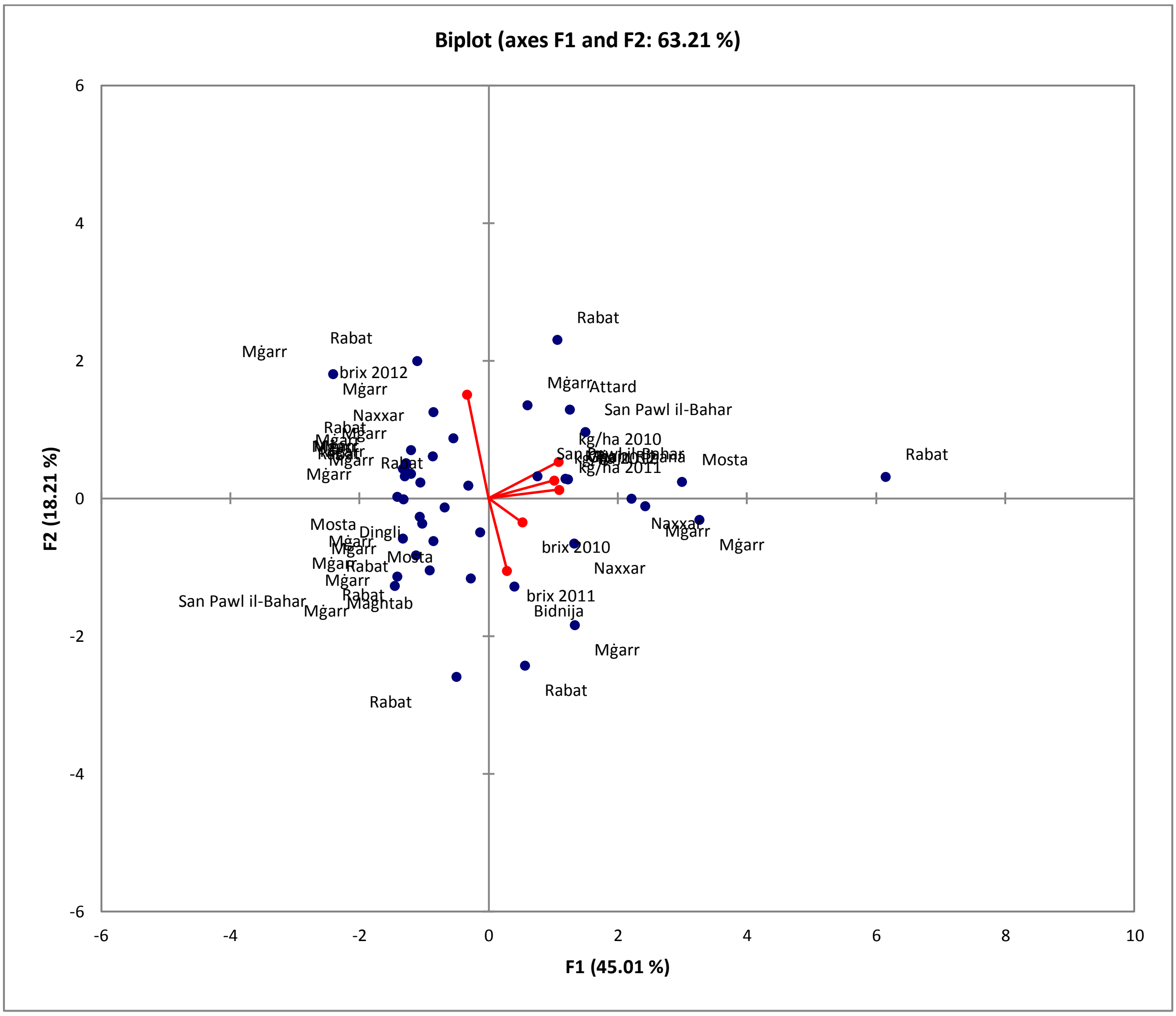

Figure 12 – PCA plot showing Girgentina parcels labeled by location as affected by brix and yield levels of different seasons

The variables for Girgentina gave very similar trends to those in Ġellewża, that is, the brix variables are not showing the same trend every season, while the yield is pointing to the right of the figure above. Again, a vineyard from Rabat is shown as having the best yield but the locations are randomly spaced out with no trends observed.

The trends in these two PCA plots indicate that when considering the small size of the island of Malta, and considering that the vineyards with the indigenous varieties are mostly found in the same area in the western part of Malta, the differences observed in the locations are over shadowed by other differences such as management practices that possibly effect the brix and yield much more than the location. This indicates that the quality of the grapes of both indigenous varieties cannot be distinguished by the location of the vineyard within Malta.

4.4 Interviews

A total of 30 growers, 15 for each variety, were interviewed in this project in a series of visits held between July and August 2013. The interviewed Girgentina growers had an average vineyard size of 0.435 ± 0.282 ha and covered a total area of 6.530 ha while the interviewed Ġellewża growers had an average vineyard size of 0.479 ± 0.554 ha and covered a total area of 7.185 ha. Growers having both varieties were only listed under one variety to ensure that 30 different individuals are interviewed; however since they were listed under one variety, the vineyard size of the other variety is not accounted in the quoted values. Furthermore, the selection was taken from a number of growers that supply grapes to one of the two major companies that produce wines from Ġellewża and Girgentina commercially and only from those who had at least 0.100 ha of vines, not necessarily in a single parcel of land.

The average altitude for the Ġellewża vineyards was 85 ± 50 m while that for Girgentina vineyards was 123 ± 46 m. The Girgentina vineyards interviewed were found to be statistically significantly higher altitudes than the Ġellewża vineyards at 0.05 level of confidence, however the difference in average is only about 38 m and therefore it is not likely to make a difference between the varieties on the quality of the grapes produced.

Only 5 of the 30 growers were registered as full-time farmers and none of them earned their living solely from growing grapes, let alone solely from Ġellewża or Girgentina. The full-time farmers had more parcels of land apart from those with the indigenous varieties and also grew a number of other fruit and vegetables that are sold in the local market or exported.

6 of the growers interviewed were members of the viticultural producers' organization (PO) in Malta known as VitiMalta. Some other growers indicated that they were members of other cooperatives and organizations but since it was not specified in the interview script, no further details about these memberships were taken, especially considering that these were never directly related to viticulture. Lack of interest in the producers' organization can be probably because it was established for growers of international varieties who invested substantial amounts of money and is not focused on the viticultural practices of growers of indigenous grape varieties. Furthermore, since most growers would have grown vines for a long time, mostly as a hobby, they wouldn't be interested in being members of the PO with the obligation to sell their grapes to the company decided by the PO and also giving a commission from their gross profit.

4.4.1 Vine training, pruning and support

From the 30 growers visited, only 1 Girgentina grower and 1 Ġellewża grower had vines trained on a trellis. All the other growers trained their vines as bush vines without a permanent support structure, although some growers used materials such as pieces of reed stems to support the main canes so that the grapes on them do not touch the soil.

Figure 13 - A Girgentina field showing bush vines with no structural support

The low bush method of vine training is convenient because it reduces the capital cost required to set up the vineyard. It is probably also used because it protects the vines from wind more than the trellis systems (Meekers, 2006), since the latter tend to expose the vine to the possibility of wind damaging the fragile shoots after bud burst. Trellising is advantageous in large vineyards as they allow for mechanical harvesting, something that is not financially feasible in Malta due to the small sizes of the vineyards.

All growers used the cane pruning method, with the number of canes left on each vine is usually decided by the grower according to the vine’s strength, however most growers claimed that they leave 2 or 3 canes. The length of the cane is also variable and can have between 5 to 10 buds in each cane, but at least 6 growers claimed that they usually leave the cane length at about 30 cm to 40 cm, without counting the buds.

Not all growers leave renewal spurs. 12 growers did not mention any renewal spurs in the interview, 8 said that they leave 1 spur in each vine, 4 said that they leave 1 or 2, while the other 6 growers said that they leave 2 spurs. None of the growers mentioned that they carry green pruning or bud rubbing later in the season.

The training on the Maltese indigenous varieties is therefore different from the 'Gobelet' training system which is a popular bush vine system based on spur pruning. The consistency of cane pruning in the Maltese indigenous varieties suggests that the growers learned through experience that cane pruning gives the best results and they prune their vines in response to the vine's strength in the previous season, that is, they allow more buds and canes on vines showing high vigor, and perform heavier pruning on less vigorous vines.

4.4.2 Vines per hectare

The average planting density for the interviewed growers was found to be 2058 ± 907 vines per hectare. The average density of Girgentina was 2186 ± 894 vines per hectare while that of Ġellewża was 1930 ±932 vines per hectare. The two varieties did not show significantly different planting densities at 0.05 level of confidence. There was also no significant relationship observed between planting density and altitude at 0.05 level of confidence.

Vines are usually planted at distances of 1.8 m to 2 m apart from each other in all directions, meaning that the planting density should be of about 2500 to 3000 vines per hectare. The main reason for the lower planting density observed is due to the missing vines that are not replaced. A number of wild vines to be used as rootstocks were observed in many vineyards but these still need to be grafted. A general lack of initiative to graft these vines was observed.

The usual planting density of international vines in Malta is 5000 vines per hectare (Meekers, 2006). This is because these are planted in rows that are also 1.8 m to 2 m apart, but within each row, the vines would be planted just 0.9 m to 1 m apart, mainly because all these vines are irrigated and can supposedly withstand the competition between nearby vines. In bush-trellis trained vineyards in Sicily, the number of vines per hectare can vary from a minimum of 7000 vines to a maximum of 11000 (ProMed, 2013). Since many indigenous vines in Malta are not irrigated and do not have support structures, they are left further apart to reduce the competition and ensure that the canes can sprout in different directions without touching the nearby vines.

Figure 14 - Indigenous vines with good vigor sprouting in all directions covering much of the soil with the extensive canopy.

4.4.3 Nutrition

The soil characteristics influence the strength of the vine and the quality of the grapes. The different soil types of Malta along with different geographical features that can affect the physico-chemical characteristics of the soil can all have an influence on how the vine performs. However, unlike weather conditions which cannot be much predicted and controlled, the influence of soil characteristics can be considered as secondary (Meekers, 2006), especially because these can be altered and many times improved by good management practices and by the appropriate choice of rootstock. The addition of nutrients is one of the most common practices in this regard. The interviews showed that the most common nutrient used is the slow release compound fertilizer NPK 12-12-17, which means that it contains 12% N, 12% P_2O_5, and 17% K_2O. This is usually applied sometime between October and March, and 12 growers out of the 30 interviewed claimed that they apply it between December and February, something that goes against the EU Nitrate Directive. The reasoning for this timing chosen by the growers is that they need to apply it some two to four months before the vines start to sprout the new growth. This is applied in powder form and it will be slowly dissolved by rain. Applying that type of fertilizer after mid-March as stipulated by the EU Nitrate Directive would mean that the nutrients are not well dissolved, especially considering that very little rain falls between April and July. On the other hand, applying it before mid-October would result in the loss of most of it before any is used by the vines. It is uneconomical and not sustainable to apply fertilizers in a period when the vine is not growing, since the nutrients put in soil may get leached into the groundwater or carried away by surface runoff. In some cases, when nitrogen is present in the fertilizers it can also be lost by volatilization that releases ammonia gas or by denitrification to the atmosphere.

Here one needs to question whether this nutrient or application of other nutrients such as ammonium nitrate, that were also mentioned in the interviews are actually needed, because it is apparent that most growers apply them annually or bi-annually by tradition, without any actual scientific data of what nutrients are deficient in the soil. It is also not ideal to apply a fertilizer without knowledge of the current soil nutrients available in the soil (Vella & Kuecke, 2003). Such information can only be obtained through soil analysis. The Maltese Code of Good Agriculture Practice suggests that soils should be analyzed for their phosphorus and potassium status every 6th year, while pH and salinity levels of the topsoil should be checked regularly (Vella & Kuecke, 2003).

7 growers mentioned the application of organic pellets, some use is in September or October, others in January or February, while others apply it later in March. Using organic pellets would be giving a wider variety of nutrients while also helping the soil quality due to the increase in organic matter. 3 growers claimed that they do not give any nutrients whatsoever. Unfortunately none of the growers interviewed mentioned intercropping or mulching. This means that for most of the wet season the soil is left exposed, which apart from being a cause for soil erosion, it is also a waste of space that can give some yield of legumes which also increase the nitrogen content through nitrogen fixation.

4.4.4 Plant protection

Fungal diseases are one of the major threats to grape produce every season and it is a common practice for growers to spray their vines as a precaution and also to cure the first signs of diseases. All the interviewed growers confirmed that they protect their vines from fungal disease using plant protection products. The majority of the growers start spraying in April or May, but some have also stated that they start earlier or later as shown in Figure 15:

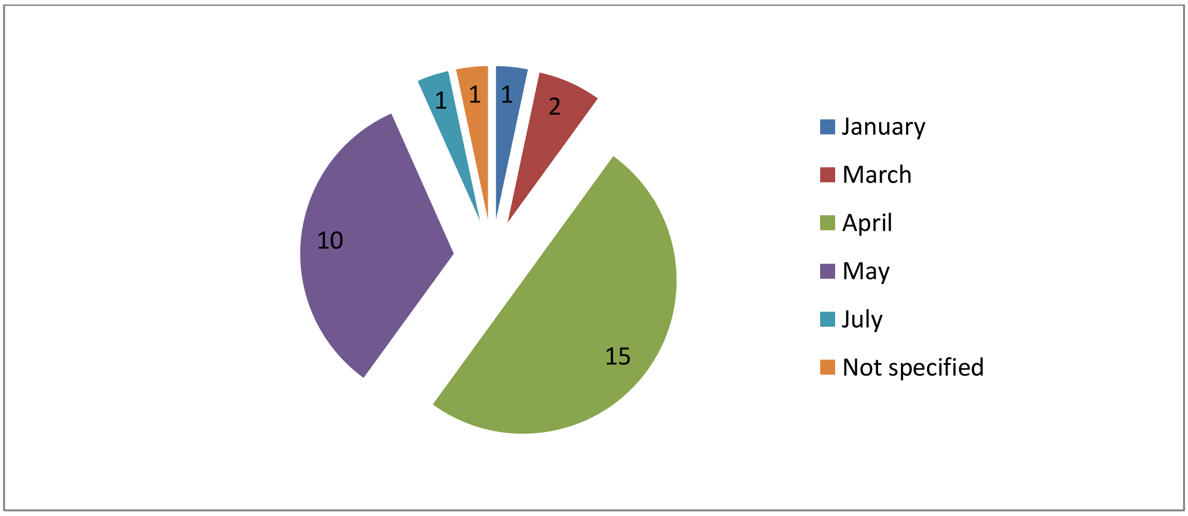

Figure 15 - A pie chart showing how much growers start spraying in which month

Spraying is most effective as from the start of bud burst, especially in vines that already had diseases in the previous season. Powdery mildew is especially known to stay on the vine and appear in the following season. April is the ideal time for spraying because it is when the first leaves start developing. By starting the application of plant protection products in May one can risk that fungal diseases may accumulate and then it will be more difficult to control because the number of leaves would be much more. Having the first spray in July is even a further risk and can only be effective if the weather and biotic conditions are favorable and when no diseases are present. It is very difficult to cure a disease by starting spraying in July when the berries have already formed.

Plant protection also depends on how regular the products are applied. Ideally the growers check their vines regularly and only spray when they see that the weather conditions are not favorable or when the first signs of diseases are observed. However, one cannot always use these strategies, especially due to time constraints and lack of technical knowledge. For this reason growers tend to follow pesticide programs given by winemaking companies, agriculture organizations or pesticide suppliers, or else they would spray products at regular intervals for a set period to ensure that the vines are protected as shown in Figure 16:

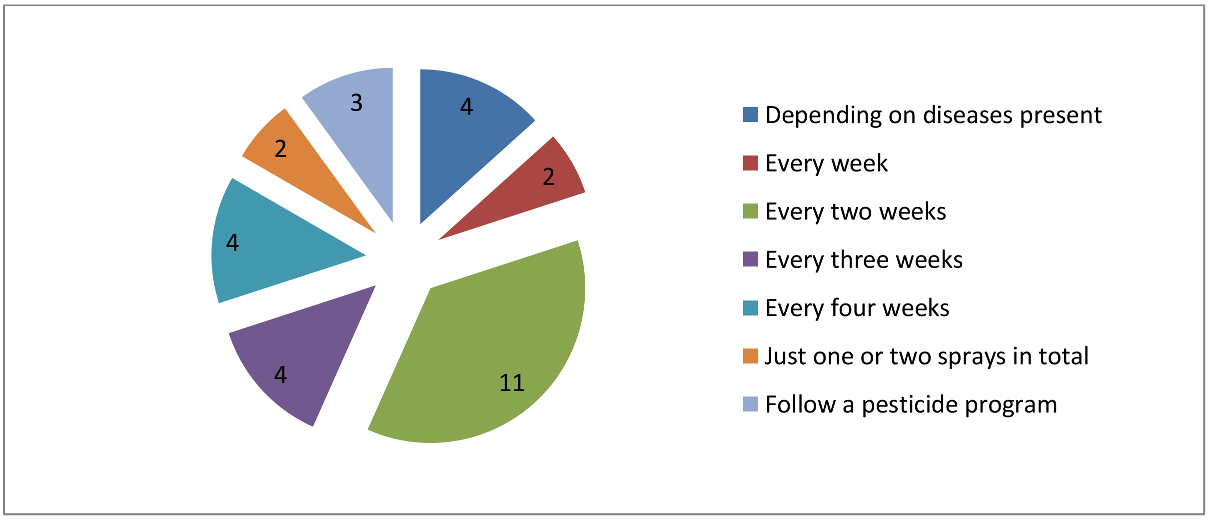

Figure 16 - A pie chart showing the frequency of spraying by different growers

The frequency of spraying was found to be very difficult in the interviews. Different growers may have different experiences that lead them to choose a particular frequency; some try and avoid diseases at all costs by spraying regularly while others try to spray as minimum as possible. Those who claimed that they spray ‘depending on diseases present’ explained that they would visit the vineyard regularly to check the vines and would also spray after days of rain and cold periods. Those who follow a pesticide program usually started spraying in the last week of March or first week of April and then sprayed every two weeks until flowering and then every week during flowering. Then they would keep on spraying again every two weeks until the first week of July. The time at which growers stopped spraying was also investigated and the results are shown in Figure 17:

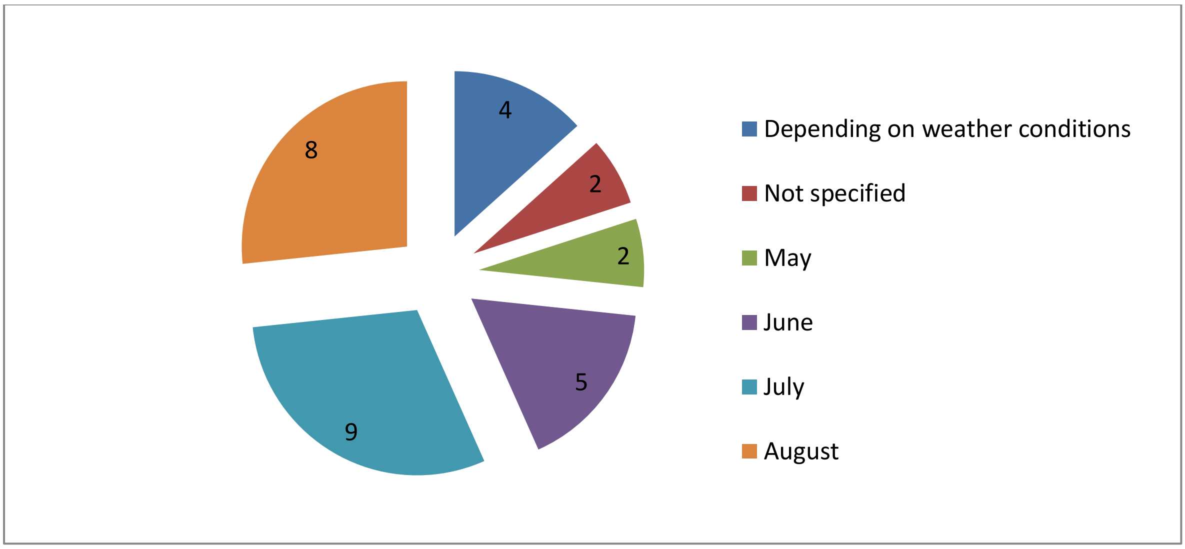

Figure 17 - A pie chart showing when growers stop spraying, classified in different categories

The decision to stop spraying can vary according to the conditions of the particular season, and even after one decides to stop spraying, one can still spray again should the conditions require. In fact 4 growers specified that they decide according to the weather conditions every season. Stopping the application of protection products early, such as in May or June, can be a risk because the berries would still have not matured enough. After the berries are mature, it is much safer to stop spraying, especially considering that the weather conditions in Malta in July and August do not promote fungal diseases. Stopping all product application in August is essential to allow for the withdrawal period of the products to pass before harvest.

A variety of plant protection products are used and some use a combination of products to ensure that diseases are eliminated and to avoid the formation of resistant populations. Sulfur and copper sulfate are very common but a number of growers also chose to use a combination of systemic fungicides that are available in the local market after being registered with MCCAA. The replies of the growers regarding what protection products do they use against fungal disease is shown in Figure 18:

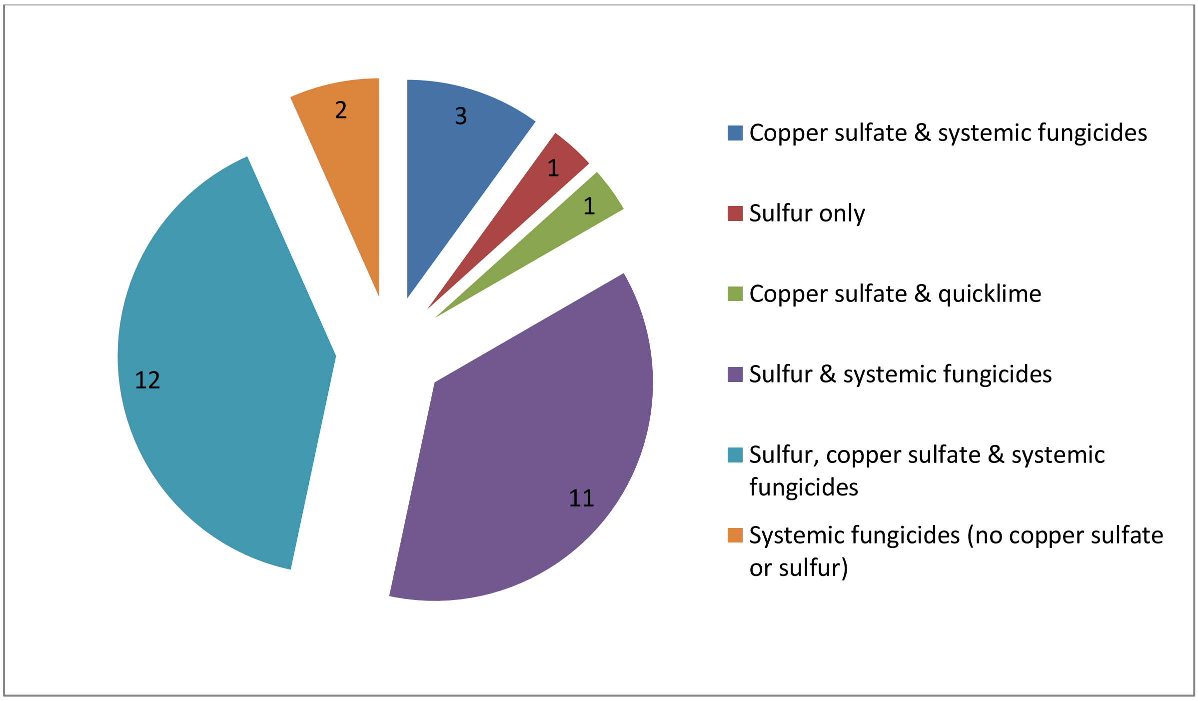

Figure 18 - A pie chart showing the different categories of spray used and by how many growers

As expected, sulfur was used by 24 out of 30 growers making it the most product used while copper sulfate was used by 16 growers. 28 growers also included systemic fungicides in their plant protection strategy, however details of these products was not collected as it was beyond the scope of this project.

A new option for improving disease resistance in vineyard management is through the use of transgenic grapevines, which can produce anti-microbial peptides that can make the plant resistant to bacterial and fungal infections (Rosenfield, Samuelian, Vidal, & Reisch, 2010). This research is very technical and requires a lot of expertise, however promising results has been achieved against bunch rot and crown gall. Rosenfield *et al*. (2010) reported that there are no known antimicrobial peptides that were found effective against powdery mildew, one of the most common diseases in Malta.

14 growers also used insecticides to protect their vines. The European Grapevine Moth, *Lobesia botrana*, is one of the most common insects that attack the vine and growers usually spray in July and August to protect their produce from insects. Those spraying in August in the figure above can include those using insecticides, and not necessarily spraying fungicides in August. Those using insecticides also need to take note of any withdrawal period of the product to ensure that the grapes would be ready to be harvested by the first week of September, because the winemaking company may decide to harvest anytime in September, although harvest of Ġellewża and Girgentina usually takes place between the second and third week of September.

The use of herbicides is not common because growers prefer to control the weeds by cultivating the soil. Only 1 grower mentioned the use of herbicide in his vineyard, and it is applied in February so that the vineyard would be free from weeds at bud break.

4.4.5 Irrigation

18 out of the 30 interviewed growers did not irrigate their vines. Another 2 irrigated some of their vines because water was not available in all their vine parcels, while the other 10 irrigated all their vines. From the 12 growers who irrigated their vines, 9 used borehole water from the mean sea level aquifer, including the two growers who

irrigated some of their vines, 2 growers used water from the perched aquifer, while 1 grower used water from rainwater harvesting as explained in Figure 19:

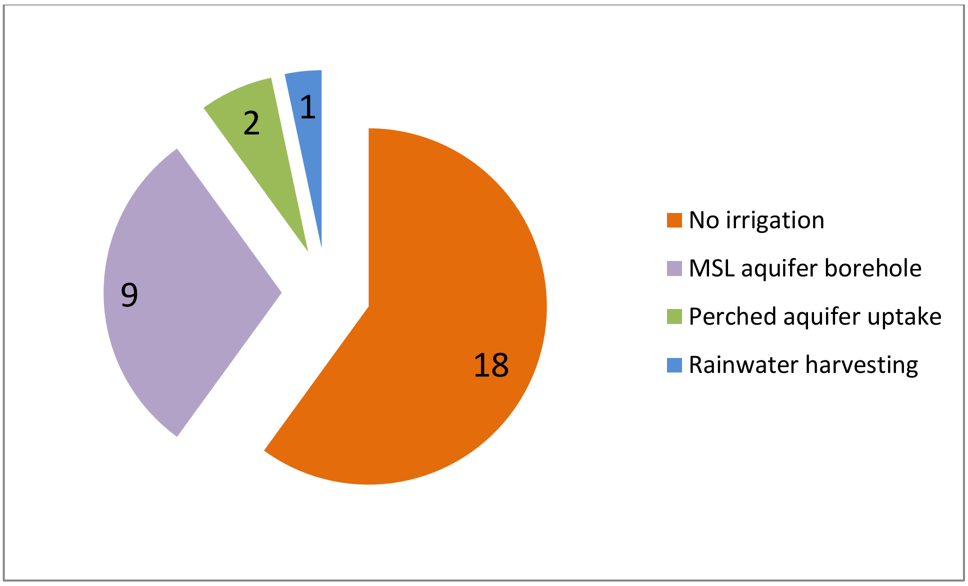

Figure 19 - A pie chart showing number of growers that use different sources for irrigation

Irrigation of vines, where present, was always done using drip tape which had emitters at regular intervals. This differs from irrigation usually present in trellised systems, more common for international varieties, where the drip irrigation systems have a nozzle between every two vines.

Figure 20 - A Ġellewża field with one of the drip tapes shown going across the length of the field

The advantage of drip tape is that it can be spread on the soil and can provide water all along the area where it is spread, ensuring that the roots are not focused in just one or two areas. However, nozzles usually allow a specific amount of water to flow out of them every hour, which would help the grower have a better knowledge of how much water is being given to each vine, while assessing how much water is given per vine using the drip tape is not very straight forward. The other disadvantage with drip tapes is that they need more maintenance, and need to be completely replaced after a few years, since they are spread on the soil and thus are more susceptible to clogging and to damages from animals such as rodents. With costs for equipment increasing, the regular need for maintenance and replacement of drip tape may be one of the reasons that many farmers do not irrigate their vines, as the additional irrigation will not improve the profit to an extent that the costs and additional work will be made worthwhile.

Irrigation does not only supply the vines with water at a much crucial stage when they are highly stressed due to the summer heat, but also gives the opportunity for fertigation practices, that are highly recommended (Vella & Kuecke, 2003) since they can allow for fertilizer to be given only when it is needed and in controlled amounts.

A PCA test using Pearson correlation was carried out using the brix and yield data of the interviewed growers to check out if the irrigation is making any significant differences in the brix and the yield of any of the two indigenous grape varieties. Only the data of growers that sold grapes in all three seasons were used. For each variety, the growers that irrigate their vines were labeled with I, meaning irrigated, while those who did not irrigated were labeled with NI, meaning no irrigation. The following plot was obtained:

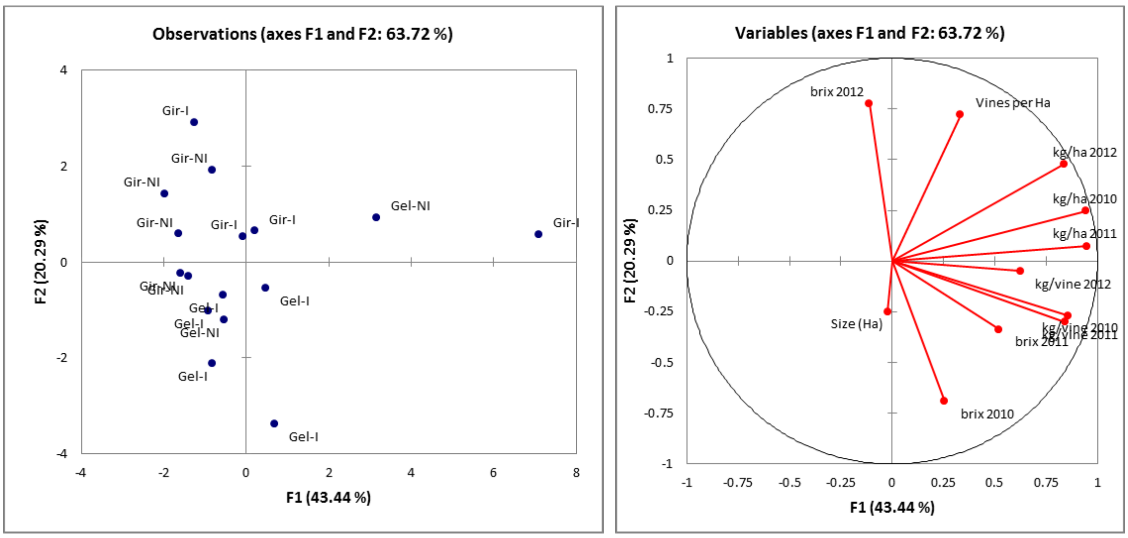

Figure 21 - PCA plot (shown on the left) for the analysis of irrigated and non-irrigated vineyards using various variables (shown on the right)

In general, according to the factor F1, the non-irrigated vineyards showed lower yields (found more to the left) than the irrigated ones. The variables indicate that the higher yields for every season are towards the right side of the plot, while the brix values for different seasons do not show any trend. There are more irrigated vineyards on the right hand side for both Girgentina and Ġellewża, showing that irrigation is effective in increasing the yield, but this is not observed in all irrigated vineyards. Furthermore, one non-irrigated vineyard is found showing high yields too, indicating that irrigation is not the only factor contributing to high yields. These observations indicate that it is most likely that vines growing in particular locations may need more water than others, probably due to the soil characteristics. In all grape growing areas around the world, the physical properties of soil are recognized to be of major importance with the most important consideration is to have well drained soils that can also provide moisture throughout the whole growth cycle (Dry & Coombe, 2004).

The results show that irrigation improves the yield but non-irrigated vineyards with good yields are also possible to find. The results also show that irrigation is not resulting in any effect on the brix, something that is concern to a lot of growers. Here one must also point out that in this study, all irrigated vineyards were classified in one category and that very limited data were available. More detailed studies should also include the frequency, amount and during which period irrigation occurs, as these could have different effects on the brix and yield. These studies would also be ideal to ensure that irrigation water is used more effectively to ensure the sustainable management of the local freshwater resources.

4.5 Irrigation water quality

A total of 33 samples collected, 3 replicates from 11 growers, however one of the samples collected was from a source used by two growers, so a total of 12 growers from the 30 growers interviewed had irrigation water.

The borehole water had an average conductivity of 3039 ± 2030 µS/cm and an average chloride concentration of 615 ± 419 ppm, with the 5 samples from the Għajn Rihana region all having higher conductivity and chloride levels than those in Mosta, Rabat, and Żebbuġ.

The two samples from a perched aquifer had conductivity values of 2485 µS/cm and 1890 µS/cm and chloride concentrations of 488 ppm and 405 ppm. As expected, the sample from rain water harvesting had the lowest values, which were 699 µS/cm for water conductivity and 57 ppm for chlorides.

A direct relationship was observed between the water conductivity and chlorides as can be observed in Figure 22:

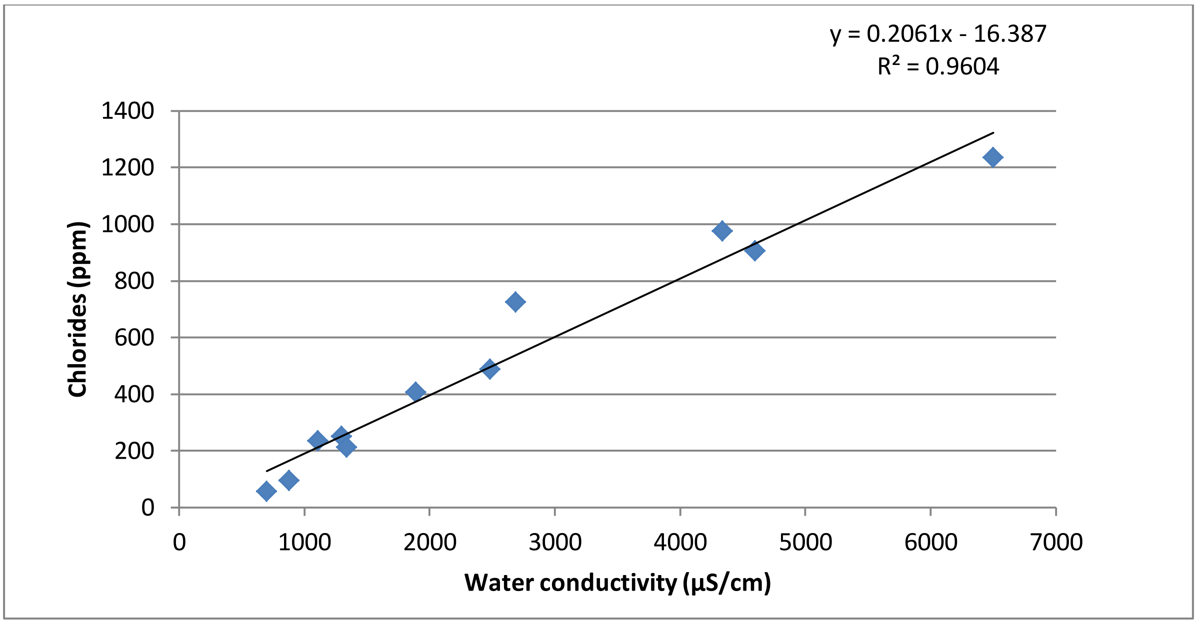

Figure 22 - Correlation between water conductivity (µS/cm) and chlorides (ppm)

The R^2 value of 0.9604 confirms that the water conductivity is mainly being influenced by chlorides which is present in the mean sea level aquifer through salt intrusion and can also be present in other water sources through sea spray. Since the highest chloride and conductivity values were all obtained from the Għajn Rihana region, which is very close to the coast, confirms that the reason for the high values is due to salt intrusion.

The average nitrate values for borehole water was 149 ± 90 ppm, with the highest value of 280 ppm also found in the Għajn Rihana region. However, the nitrate levels in the perched aquifer samples were also found to be high at 220 ppm and 120 ppm. The nitrates in the rainwater harvesting sample were found to be at a concentration of 20 ppm. The nitrates was not found to be in a direct relationship with water conductivity or the chloride values as can be observed in Figure 23 and Figure 24:

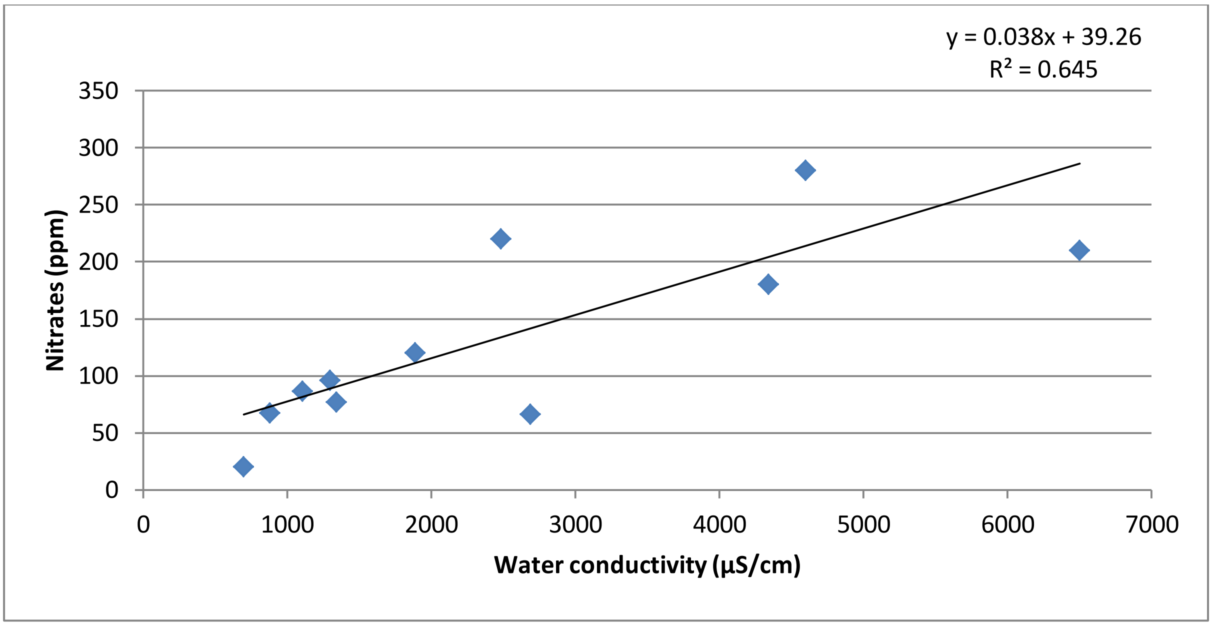

Figure 23 - Correlation between water conductivity (µS/cm) and nitrates (ppm)

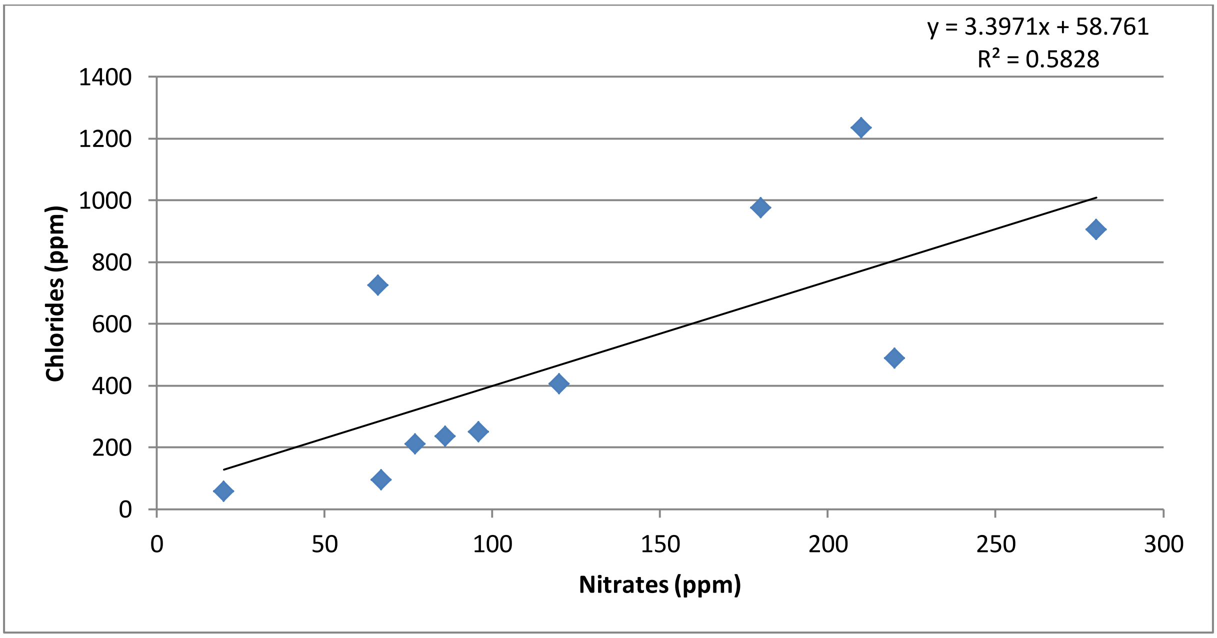

Figure 24 - Correlation between nitrates (ppm) and chlorides (ppm)

The high levels of chlorides, also contributing to high water conductivity are mainly caused from over pumping while the source of nitrates is generally the over use of fertilizers which leach to the ground water (Schembri, 1993). Since these have different sources, it is to be expected that there is no direct relationship between the values obtained. However, from the figures above one can observe that where the water conductivity and chlorides are high, nitrates are also high, confirming that both are a result of intensive farming. This puts a lot of concern on the Għajn Rihana region, which includes: Burmarrad, St. Paul's Bay and parts of Mosta and Naxxar as the quality of water in this agriculture intensive area is not good. It is most likely that the depleted quality is not a result of the management practices of the indigenous varieties, but rather of other more water intensive and nutrient demanding crops that are also cultivated. The cultivation of indigenous varieties might actually reduce the demands for water and nutrients and can help in the long term regeneration of the water quality in the area.

The data for water quality was also analyzed using a PCA with Pearson correlation, as shown in Figure 25:

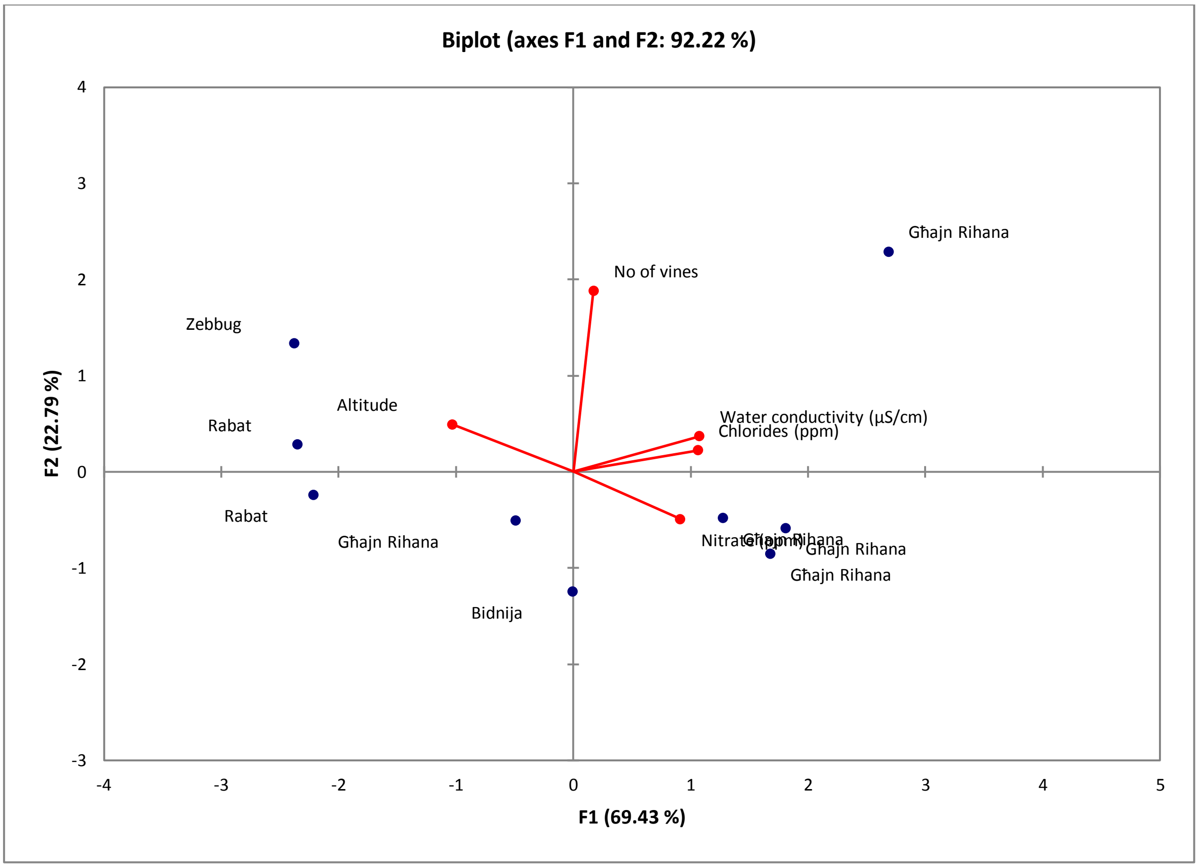

Figure 25 - PCA plot showing the effect of water quality on vineyards labeled by location

The positive F1 (right) plotting confirms that the area with high nitrates, chlorides, and water conductivity is the Għajn Rihana area. The altitude is opposite to the high concentrations of ions in water probably due to the fact that the island of Malta is tilted seawards to the northeast and therefore as the altitude decreases, the closer one gets to the sea, thus the effects of salt intrusion are more expressed. Surface run off could also be possibly redistributing nitrates to low lying areas, which then leach and settle in the ground water at very high levels. Higher altitudes may also have the possibility of using water from the perched aquifer.

A further PCA with Pearson correlation was performed, including brix and yield data for the three seasons along with the water quality, to understand the effects of water quality. Here one must note that the brix and yield values were obtained from the harvest of 2010, 2011, and 2012, while the water samples were collected in 2013, therefore these results are only indicative of the water quality in the previous years. Figure 26 shows the plot obtained:

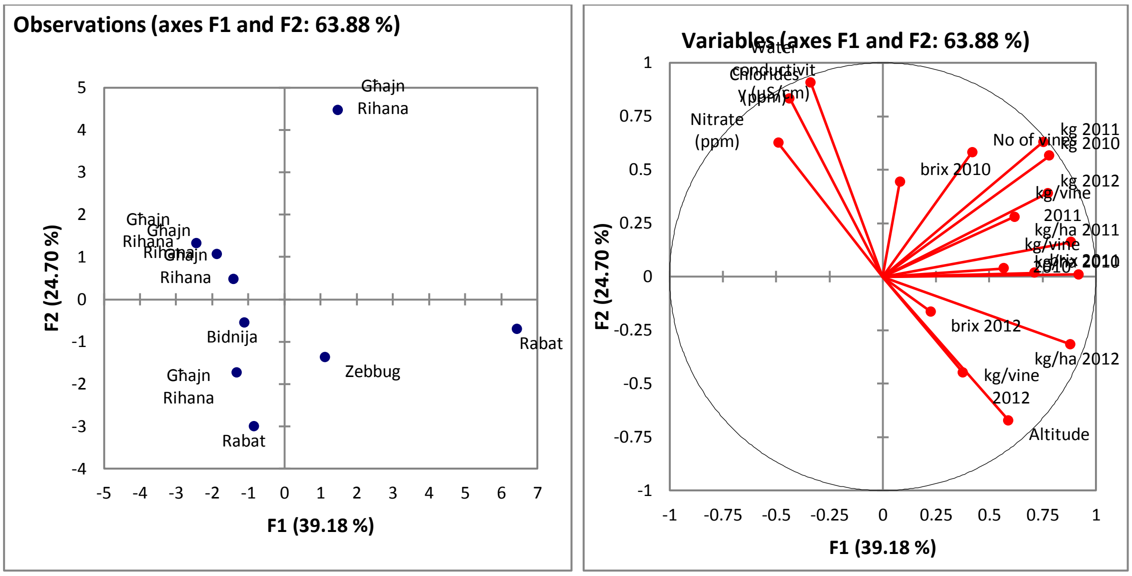

Figure 26 - PCA plot (shown on the left) showing the effect from various variables (shown on the right) on vineyards labeled by location

The F1 factor, which includes grape yields, shows that Għajn Rihana vineyards had lowest yields. According to F2, the water quality in this area was poor due to high content of nitrates and salts.

The variables plot did not show a direct relationship between water quality and yield for all years, but indicates that there is a lower yield when the water quality is reduced. One may argue that a high level of nitrates can improve the plant vigor and the yield, but since these were found in areas with very high water conductivity and chlorides, it is most likely that any positive effect that the nitrates might have is being overshadowed by the problems related to water conductivity and chlorides. The Għajn

Rihana area is clearly suffering from reduced yields due to the low quality irrigation water.

4.6 The economics of vineyard management

4.6.1 Subsidies available

Subsidies for farmers are administered by the Malta Agriculture and Rural Payments Agency, which works to maximize the benefits from the Common Agricultural Policy (CAP) by processing payments and receipts, ensuring compliance with EU rules and regulations, and giving out information to the farming community (MRRA, 2013). The main subsidies available to vine growers fall under the 'IACS based measures', specifically under measure 214 of the Rural Development Plan for 2007 – 2013 which are aimed to promote sustainable practices and consist of the following nine Agri-Environmental Measures (AEMs):

1. Use of environmentally friendly plant protection products in vineyards
2. Traditional cultivation of sulla through crop rotation
3. Low input farming
4. Suppress the use of herbicides in vineyards and fruit orchards
5. Establishment and maintenance of conservation buffer strips
6. Conservation of rural structures providing a natural habitat for fauna and flora
7. Providing a healthy forage area for bees
8. Support for Organic Farming
9. Support for the Conservation of species in danger of genetic erosion

For one to participate in any of the first eight measures, one needs to have a minimum of one tumolo (1124 m^2) of continuous land that can be used for agricultural purposes. Agri-environment measures compensate farmers for voluntarily entering a 5 year commitment to carry out practices that are considered to be beneficial for the environment. The participants are also required to participate in a free training module organized by the Rural Development Department within the first two years from applying (MSDEC, 2013). A farmer can only apply for one measure per parcel of land owned, however measures 1 and 4 or 2 and 3 can be taken together as a package. The funds for these subsidies are available through a co-financed system by which 80% of the funds are provided by the EU and the other 20% are made available from a national fund (MRRA, 2013).

Unfortunately, the first AEM, intended to reduce the use of plant protection products and to give financial aid to growers to cover vines with appropriate netting to prevent bird damage, is targeted only at vineyards using trellised systems and therefore the majority of vineyards with Ġellewża and Girgentina are not eligible for this subsidy. Vine growers are not eligible for the second and third AEM, but they are eligible for the fourth AEM, intended to suppress the use of herbicides in vineyards and fruit orchards. Under this measure, growers are obliged to maintain a suitable inter-row vegetative cover between 31st October and 1st March and therefore both tilling and herbicide use is prohibited, however the control of excess vegetation by means of a grass cutter is allowed, which is beneficial as this would serve as a green mulch (MSDEC, 2013). Some growers claimed during the interviews that one of the reasons for not using herbicides is because they are subscribed to this measure. Most of the growers did not mention the use of any herbicides during the interviews so this measure is leaving the desired effect in relation to the management of the indigenous grape varieties, and it is the one which is most convenient for the vine growers to apply for as the requirements are not very challenging. To participate in the fourth AEM, farmers are given an annual payment of €67.92 per tumolo for five years (MSDEC, 2013).

Another interesting but more challenging AEM is the eighth one, which gives support for organic farming. In this measure, the extent of financial support varies according to the conversion status and the crop being cultivated. Vineyards under conversion to organic receive an annual payment for five years of €111.95 while certified organic vineyards receive €89.56 for the same period (MSDEC, 2013). None of the interviewed growers have opted to this scheme, which could possibly be due to the fact that the financial incentive is quite low when considering the challenges of organic farming. Furthermore, since the parcel sizes are small and the grapes are sold to a winemaker who buys grapes from different growers, even if a grower would opt for a personal decision to produce organic grapes for his environmental values, the winemaker cannot be expected to pay a higher price for those grapes because the quantities would not be enough to produce an organic certified wine at a commercial scale from the grapes of just one or few growers.

4.6.2 Price of grapes

The income from growing grapes is totally dependent on the yield and quality of grapes achieved by harvest and growers work hard to ensure that the highest possible yield and quality are obtained. In Malta, when grapes are sold to a winemaking company, they are weighed and the sugar levels are checked, and the growers are paid according to the number of kilograms they have harvested. The payment is usually given out some months after the actual harvest.

The prices for Ġellewża and Girgentina grapes are different and there are also different prices for DOK, IĠT, and TW grapes, as shown in Table 13:

Table 13 - Prices per kilogram for the different classifications for both varieties

Category	Ġellewża (price per kilogram)	Girgentina (price per kilogram)
DOK	€0.52	€0.48
IĠT	€0.44	€0.40
TW	€0.34	€0.30

The prices shown in the table above show that for every category, the price for Ġellewża is always slightly higher than that of Girgentina. This is most likely due to the fact that there is much more Girgentina vines in Malta and so the demand for Ġellewża grapes is higher. This means that Ġellewża growers obtain higher yields on average and more profit per kilogram than Girgentina growers. Good quality grapes can be sold in farmers' markets as table grapes for higher price; however there is a demand limit in the Maltese market and therefore it is not something that all the growers can do. Grapes harvested from international varieties grown in Malta for winemaking are usually sold at prices ranging from about €0.55 up to €1.00, however, the amount of work required and costs needed to grow non-indigenous grapes are generally higher too.

In order to understand what price growers would consider as most reasonable for their grapes, they were specifically asked to give out a price per kilogram for their grapes in the interview, without considering the QWPSR classifications. From the 15 growers interviewed for Ġellewża, one refused to give out a value claiming that it is a personal hobby and not being done for profit. From the other 14 growers the average price per kilogram stated was of €0.60 ± 0.15. For Girgentina, two refused to give out a value and from the remaining 13 growers; the average price per kilogram stated was of €0.59 ± 0.18. One can note that the prices demanded for each variety are very similar, probably due to the fact that most expenses incurred during the year are similar for both varieties. It was expected that given the choice, most growers would ask for higher prices, however some did claim that the current prices are good for them. Others, especially those who irrigate their vines, expect more income. Many claimed that the fuel costs, fertilizers, and plant protection products all increased in price over the past years, while the grape prices did not increase in price.

4.7 Future scenarios

4.7.1 Major challenges

The management practices and weather conditions can pose various challenges on the growers. The interviewed growers were asked to identify the challenge they think that is the most difficult to perform or to overcome throughout the year. These are summarized in Figure 27:

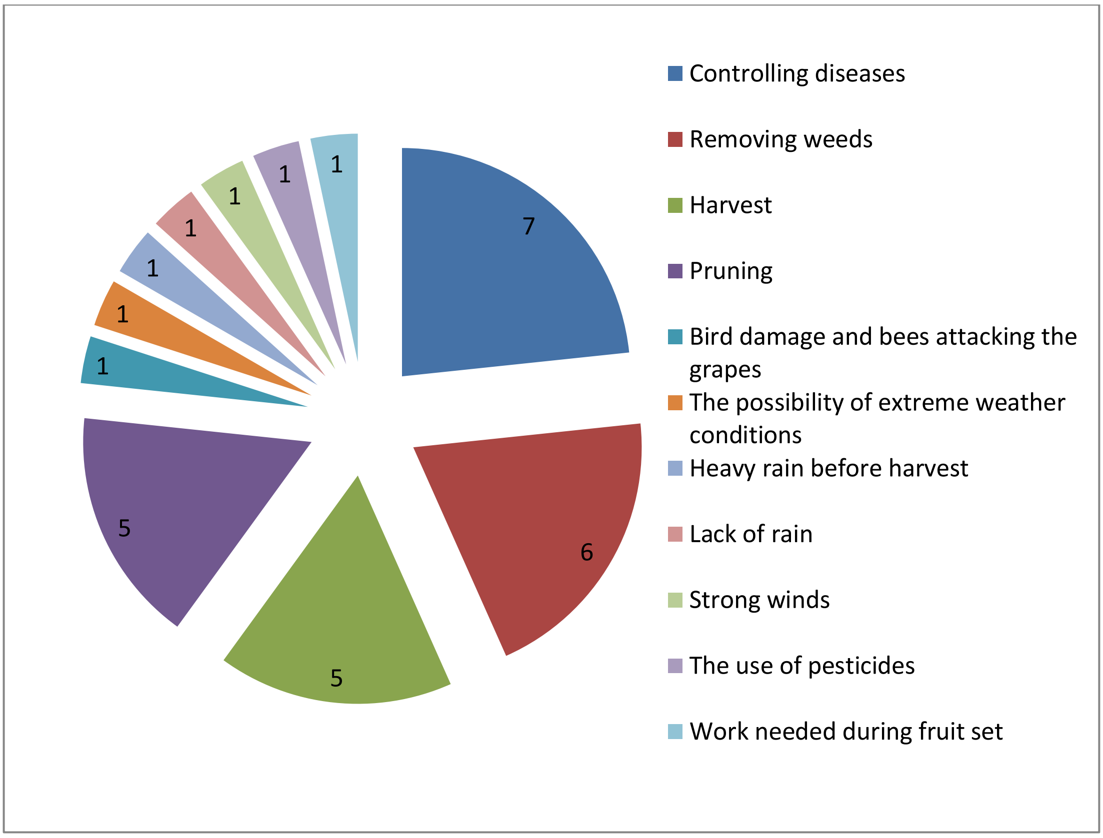

Figure 27 - A pie chart showing the major challenges identified by growers and the number of growers that identified that major challenge

Interestingly, various growers identified different challenges which are somewhat unrelated to each other. This shows that not all management practices are considered to be of the same difficulty or strain. The control of disease was discussed in detail in this project: it requires continuous attention from the growers for at least four months, it is highly affected by weather conditions, requires good use of plant protection products, many of which are expensive, and is mostly carried out using knapsack devices which can be an issue for old aged growers. Removing weeds is challenging since most vineyards do not have support structures for the vines and therefore the canes would be close to the soil making it difficult to work well with a cultivator and a tractor would damage the vines. Harvest is a challenge because all the grapes need to be harvested by hand in one or two days and although the vineyards in Malta are small, one would still need a number of people to help out in the harvest, which is quite difficult to find. Pruning requires good knowledge of vine management and it also needs to be carried out in the cold days, something that is surely challenging for the older generation of growers.

Considering these challenges and various others that were not mentioned as major challenges, one understands the dedication needed to take good care of the vines, and the frustration when the grapes are damaged or infected with diseases. Apart from the financial losses that these problems bring, there is also the personal disappointment that after so many sacrifices, one would not get the optimum out of his vines, granted that this is something that can be said for all agricultural activities.

4.7.2 The management of the indigenous vineyards in the future

This study also looked into the future of the vineyards by asking growers who they think will take care of their vineyard in ten years from now. The answers obtained are summarized in Figure 28:

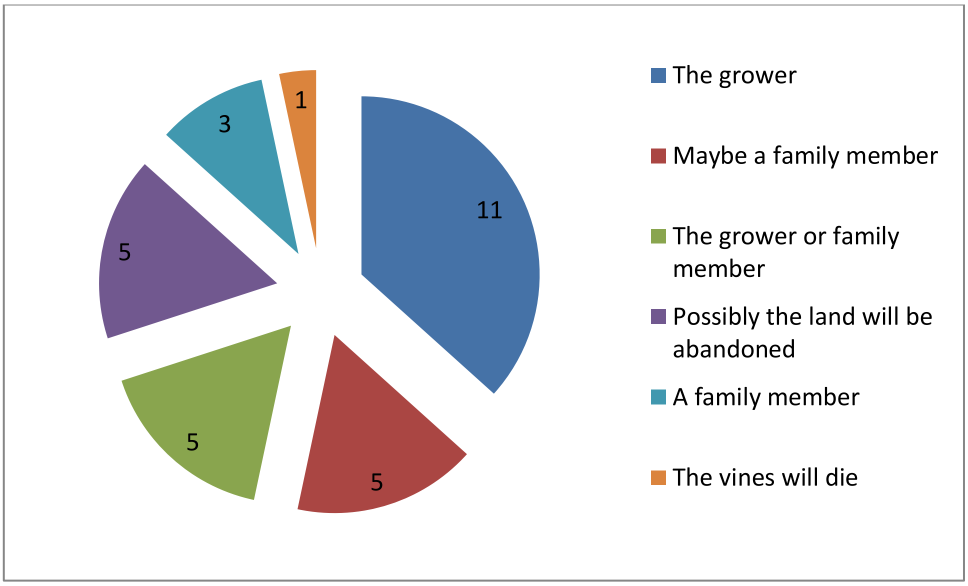

Figure 28 – A pie chart showing the persons identified to take care of the vines in 10 years' time

Even though growers claimed that the work involved is difficult and not very financially rewarding, many still believed that someone will keep on taking care of the vineyards. 6 growers claimed that the land will be abandoned or the vines will die and they will not be replaced. According to the replies obtained, the future of the indigenous vineyards is mostly dependent on the growers themselves and their family members. The advantage of having small vineyards is that even people who are not directly involved in the agriculture industry, can still keep taking care of their vineyards by dedicating some time every week during the spring and summer. Very little work, if any, is needed in autumn, and pruning is the main practice that needs to be done in winter, which can be spaced out over a number of weeks.

4.7.3 Possibility of renting vineyards

To investigate an alternative scenario for the future of the indigenous vineyards, the growers were asked if they would be interested in a scheme in which they would be given an amount of money, proportional to the size of their field, and a winemaking company will completely take care of the vineyards and then take all the grapes too. Here it was assumed that the price given out for the fields is reasonable. The idea is that growers will obtain a fixed income which is known from before. This is different from the current scenario where the income changes every year according the yield and quality of the grapes, which depend on conditions that are not always in the growers' control. 13 growers were interested in this scheme, 2 were unsure and 15 were not interested due to a variety of reasons as explained in Figure 29:

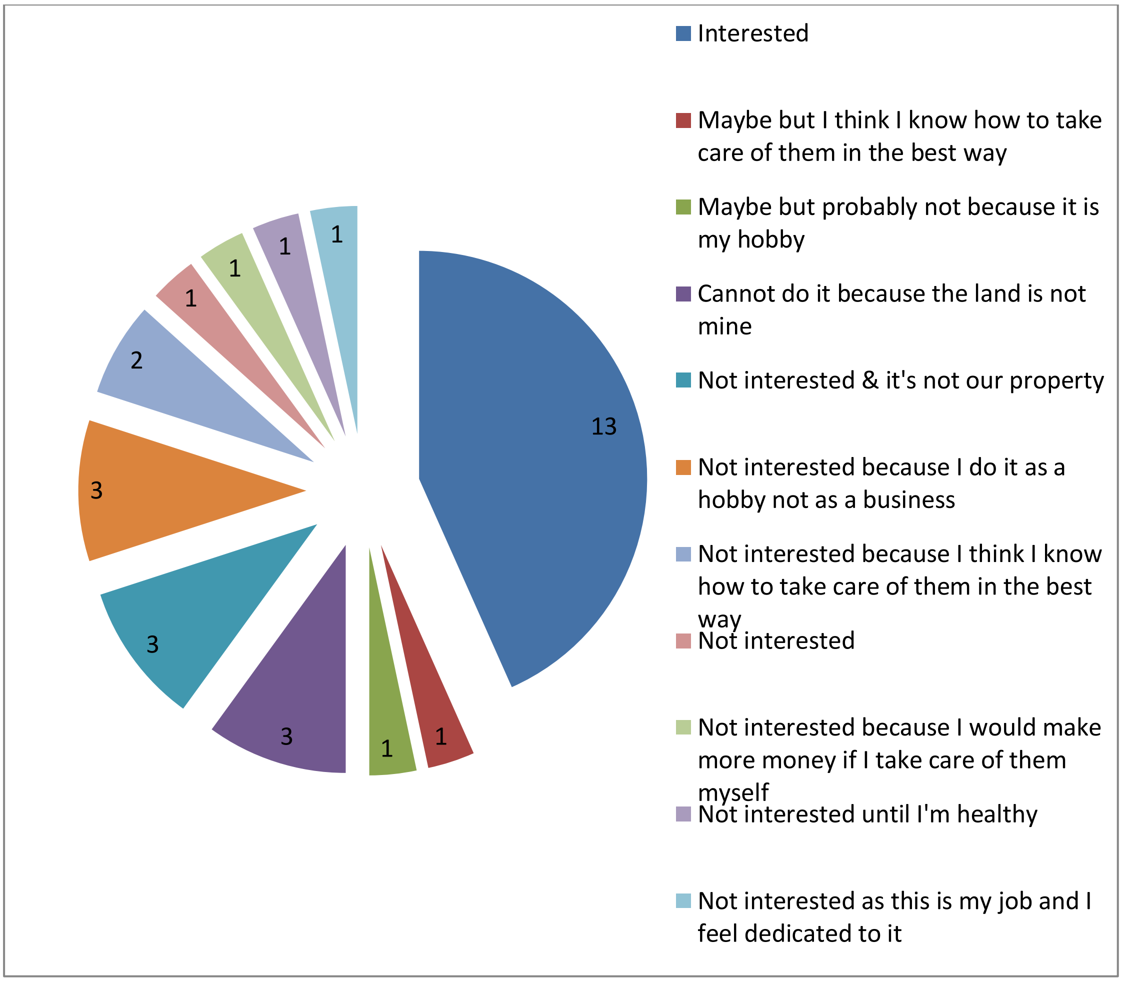

Figure 29 - A pie chart showing the replies from growers for the proposed scheme in which a winemaking company will take care of the vines

Those interested would include growers who do not know who can take care of their vineyards after they will not be able to take care of it themselves or growers who simply which to spend their time on other activities. Those uninterested were mainly growers that either do not own the land and thus cannot decide to rent it to a winemaking company, or else growers that take care of the vines mainly as a hobby. Some also claimed that since they have been taking care of the same vineyards for a number of years, sometimes running over family generations, they feel that they know how to take care of the vines best and they wouldn't trust a viticulturist that might have the technical expertise but not the experience in that field.

Such scheme would be therefore making sense for some growers and would be effective to ensure that growers who do not have any relatives who can take care of their vineyards won't abandon their fields. From a conservation perspective, one can say that schemes similar to the one proposed here are going to be indispensable in the near future considering that most growers are getting older and the number of young farmers in Malta is always decreasing. Furthermore, such scheme would encourage winemaking companies to invest in more research and equipment as they would have full control of the management practices and it would allow them to improve the practices to make them more sustainable and to yield grapes of higher quality.

5 Conclusions and Recommendations

Vineyard management is complex and is influenced by a large number of factors that need detailed and specific studies to be investigated thoroughly. Furthermore, every vineyard may have its own particular characteristics and since this study gave an overview of the vineyards of the two main indigenous grape varieties in Malta, it cannot be used to draw direct inferences, but it can identify trends that are observed and that need more in depth assessment to ensure that the management practices are the most effective, make financial sense, and in line with current policies. The trends found in this report can help the better understanding of the current scenario, however it is appreciated that correlation does not imply causation and further research is needed to investigate how the yields can be improved while using the minimum amount of natural resources as possible and leaving the least negative impact in the environment.

Research about vineyard management in Malta is extremely limited and needs to be increased much further in order to get a better understanding of how to best manage the vines in this location and what are the effects of the current management practices being used. This project was a baseline study to give a better understanding of the current scenario in the management of the two main indigenous vineyards, however much longer and more specific projects are needed to improve the management practices further for better grape quality and to ensure sustainability. Extensive research has been carried out globally about most of the international grape varieties, but very little has been done to understand the indigenous varieties of Malta.

Some form of efficient trellising or similar support structures should be considered to protect the grapes from touching the soil and thus allowing for prolonged harvest dates, but without being too high so that the vines will not be much exposed to wind. This would also help in creating the ideal structure on which netting can be placed to protect the grapes from bird damage. Bird damage is not much controlled at the moment and it is resulting in loss of yields and more opportunities for diseases. Since most vineyards do not have sturdy support structures, this issue is not given its due importance so far. Funding through subsidies to buy appropriate netting may be available.

Another management practice that is not much used by growers of indigenous grape varieties is the application of nutrients through foliar sprays. Many micro elements that are not available in the soil due to the slight alkalinity in most soils can be easily made available through foliar sprays.

With freshwater becoming ever so scarce and concerns that climate change will lead to even more harsh summer months, special emphasis should be placed on the effects of irrigation on yield. Proper use of irrigation would mean optimum profits for the growers and ensuring that water is only used when needed. Furthermore, incentives for rainwater harvesting and projects for groundwater recharge need to be increased, as these will not only be of benefit for viticulture or for the agriculture industry, but will have multiple benefits that ensure a sustainable environment for the whole country.

The Climate Change Committee for Adaptation had recommended that strong support for research is needed to understand how climate change affects Maltese agriculture and how agriculture can suitably adapt to and mitigate these effects (Climate Change Committee for Adaptation, 2010). To date this research has been limited and the need for more research in this sector is strongly felt as there are no detailed studies that are showing the effects of climate change on agriculture, let alone how to mitigate the effects. Impacts of climate change on the local viticulture may include changes in the ripening period and water stress, which may lead to changes in the patterns of pests and diseases. This will bring about greater variability in grape production, wine quality and quantity produced (Climate Change Committee for Adaptation, 2010). The National Climate Change Adaptation Strategy states that the Malta Resources Authority will establish a long-term institutional relationship with the University of Malta so that students will be encouraged to carry out research projects on the effect of climate change on different areas, including agriculture. Furthermore, it specifies that there should be strong links between the Malta Resources Authority, the Department of Agriculture, and the Institute of Earth Systems at the University of Malta (MRRA, 2012b). Being permanent crops, the effect of climate change on Ġellewża and Girgentina is especially important for farmers who have invested or are considering in investing their resources in these varieties. However, since these are indigenous varieties that have been grown for an extensive period in Malta, these might offer a higher adaptive capacity than other vines of foreign origin, but this needs to be investigated further through detailed research. The Malta Water Association recommends that farmers should be encouraged to choose varieties of crops which are water-efficient and give a good yield in local conditions (MWA, 2013), and the indigenous vines can be the best option in the viticulture sector in Malta.

The indigenous grape varieties are not being given much importance as they have been overshadowed by the increase of international varieties being grown, which produce wines perceived as of better quality and which therefore have a higher economic importance. However, when one considers the expenses needed to grow the international varieties, especially those that are not much adapted to the Maltese climate and therefore need intensive irrigation; various concerns of the sustainability of these varieties arise.

Financial incentives and the necessary technical support should be given to potential growers who wish to plant new vineyards and to existing growers who need to plant vines in parts of their vineyards. This would not only help in conserving the two varieties but also protect the soils from erosion and enrich the local landscapes.

Training to growers is needed to keep them well informed about the current policies and funding availabilities, but most importantly to ensure that their practices are sustainable and are in line with the current scientific knowledge available. Ideally these should be in the form of interactive workshops that will involve the growers' indigenous knowledge that is then linked with the scientific knowledge of professional trainers that will help the growers understand why some management practices are better than others and how to overcome the challenges they face. Through these initiatives growers can learn how to apply more sustainable practices such as Integrated Pest Management (IPM).

In the analysis of the results obtained, the use of Global Positioning System (GPS) and Geographic Information System (GIS) were restricted due to time constrains and to ensure the confidentiality of the interviewed persons. GIS can help in analyzing the data spatially allowing for a more integrated approach in the management of the environmental issues, such as that related to irrigation water and the ions present in it. This data can then be integrated to other GIS maps available, such as the soil data obtained from the MALSIS project, to give a better picture of the situation in Malta through a spatial perspective.

Users of plant protection products in Malta are required to keep a log sheet for at least three years of the plant protection products they use and record the name of the product, the time and dose of application, and the area and crop where the product was applied (MCCAA, 2013). Winemakers who collect these log sheets as part of their records in winemaking would have records dating more than three years. These records can be considered as a great opportunity for research related to plant protection of the indigenous vines in Malta. Hundreds of these data sheets could be made available to researchers which can then look in greater depth of what pesticides and insecticides are used by the growers and what effects are they having on their produce.

Once should explore further the feasibility of using photovoltaic panels in the fields to supply electricity that can be used for irrigation pumps. These would be ideal in areas where there is no electricity available and therefore replace the use of fossil fuels and the associated costs. Furthermore, in areas where a grid is available, they can be used to generate extra income during the period when they are not used. The dry season is the season with most sunlight and therefore the use of photovoltaic systems for irrigation is an ideal combination for Malta.

Various issues that need to be addressed for a more sustainable management of Ġellewża and Girgentina are overlapping issues with other agricultural activities, such as the small parcel sizes, and sometimes go beyond the agricultural sector, such as the quality and availability of groundwater. This indicates that any policy to address the various issues and recommendations mentioned in this work need to have a holistic approach in line with the pillars of sustainable development. The National Climate Change Adaptation Strategy recommended that a National Agricultural Policy should be set up by June 2013 (MRRA, 2012b), but to date, this is still not published. Such policy would be ideal to give a detailed strategy of what is to be done in the coming years and the recommendations outlined in this project should be considered for implementation.

One also needs to appreciate that more than anything; it is the demand for wine that controls the industry. There might be competition between indigenous and international grape varieties for time, resources, and profits when growers have to choose which grape varieties to grow and take care of most. However, when it comes to demand for wine, the wine produced from international varieties grown in Malta is not enough to meet the demands, and although there is harsh competition from imported wines, locals and tourists still have a great appreciation for Maltese wines. Meekers (2006) quotes Emmanuel Delicata Winemaker Limited associate director Bill Hermitage explaining that the way forward in the industry "is not so much to put out yet another classic wine on par with its foreign counterpart, but rather to bring forth excellent new wines pronouncing Malta's typicity by championing our own Girgentina and Ġellewża grapes and by pioneering with suitable international varieties." Promotional campaigns that educate the general public about the indigenous grapes in Malta could help in increasing the demand for Ġellewża and Girgentina grapes, which can also lead to increases in profitability for growers, more demands for production and more money directed in research. If Ġellewża and Girgentina are managed more sustainably, it would be of benefit for all stakeholders and ultimately all the local community.

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7 Appendix

7.1 Recruitment telephone script

Potential participants were contacted by telephone using the following script.

"Hello, my name is Jonathan Falzon and I am a graduate student at the University of Malta and James Madison University reading for a master's degree in sustainable environmental resources management. I am currently doing a project regarding the management of the main two Maltese indigenous grape varieties for winemaking.

As part of this study I am interviewing a number of growers who take care of these grape varieties and sell their grapes to Emmanuel Delicata Winemaker Ltd. You have been chosen randomly as a potential study participant from this set of growers. I will be asking you questions about your management practices to better understand Maltese cultivation of these grapes. Your answers are strictly confidential and will not be made available to anyone other than myself and my faculty advisor. Only summary data, not your individual responses, will be provided in the final study.

Please note that the participation in this study is completely voluntary, and that I will also be providing you with a written consent form should you be willing to participate. The interview should not take more than an hour and can take place in your vineyard. I will also inquire about the total number of vines that you have, and will request three water samples if you use irrigation. I will gladly provide you with the results of the tests I will do on this irrigation water, which is a water conductivity test to quantify the amount of salinity present in the water.

Also note that I currently work as a part-time trainee viticulturist for Emmanuel Delicata Winemaker Ltd. However this study is not related to my work with the company and your answers will not be made available to the company or to any other authority.

If you agree to help with this study, can we please arrange a day and time when I may come and interview you? If you would like the questions in advance, I can provide these to you in a manner that you prefer.

Thank you very much for your time."

7.2 Consent Form

Project Title: Sustainable management of the main two Maltese indigenous grape varieties for winemaking

Consent to Participate in Research

Identification of Investigators & Purpose of Study

You are being asked to participate in a research study conducted by Jonathan Falzon from the University of Malta and James Madison University. The purpose of this study is to investigate the management of the main two Maltese indigenous grape varieties which are used for winemaking, called 'Ġellewża' and 'Girgentina'. This study will contribute to the researcher's completion of his master's thesis.

Research Procedures

Should you decide to participate in this research study, you will be asked to sign this consent form once all your questions have been answered to your satisfaction. This study consists of an interview that will be administered to individual participants in their vineyards. You will be asked to provide answers to a series of questions related to the management of your vineyard and to provide three samples of irrigation water (if you use it) to be tested for water conductivity test to quantify the amount of salinity present in the water.

Time Required

Participation in this study will require no more than an hour of your time.

Risks

The investigator perceives the following are possible risks arising from your involvement with this study:

Your interview replies may be read by other people

However, these risks will be minimized because:

The interview notes with your answers will not have your name on it, only an identification number. These notes will be stored in a locked cabinet in the thesis advisor's office at the University of Malta. In addition, the information that links your name to this number will also be stored in a locked cabinet in the thesis advisor's office at the University of Malta, separately from your interview answers.

The interview notes will be shredded one year after the study is finished.

Benefits

Potential benefits from participation in this study will result in a better understanding of the management of the two indigenous grape varieties for winemaking in Malta to the scientific community, policymakers and other stakeholders. You will not be getting any personal benefits directly from this interview other than the results of your water tests, but the results of this study may eventually lead into knowing better management practices.

Confidentiality

The results of this research will be presented in the researcher's dissertation. The results of this project will be coded in such a way that the respondent's identity will not be attached to the final form of this study. The researcher retains the right to use and publish non-identifiable data. While individual responses are confidential, aggregate data will be presented representing averages or generalizations about the responses as a whole. All data will be stored in a secure location accessible only to the researcher. Upon completion of the study, all information that matches up individual respondents with their answers will be destroyed.

Important Note

I currently work as a part-time trainee viticulturist for Emmanuel Delicata Winemaker Ltd., however this study is not related to my work with the company and your answers will not be made available to the company or to any other authority.

Participation & Withdrawal

Your participation is entirely voluntary. You are free to choose not to participate. Should you choose to participate, you can withdraw at any time without consequences of any kind.

Questions about the Study

If you have questions or concerns during the time of your participation in this study, or after its completion or you would like to receive a copy of the final aggregate results of this study, please contact:

Jonathan Falzon	Dr. Maria Papadakis
Department of Integrated Science & Technology	Department of Integrated Science & Technology
James Madison University	James Madison University
falzonjx@dukes.jmu.edu	Telephone: (540) 568-8142
	papadamc@jmu.edu

Questions about Your Rights as a Research Subject

Dr. David Cockley

Chair, Institutional Review Board

James Madison University

(540) 568-2834

cocklede@jmu.edu

Giving of Consent

I have read this consent form and I understand what is being requested of me as a participant in this study. I freely consent to participate. I have been given satisfactory answers to my questions. The investigator provided me with a copy of this form. I certify that I am at least 18 years of age.

____

Name of Participant (Printed)

______________________________________ ______________

Name of Participant (Signed) Date

______________________________________ ______________

Name of Researcher (Signed) Date

7.3 Interview Script

- Are you a full-time or part-time farmer? If full-time, what other crops do you grow?
- Are you a member of the Viticulture Producers Organization of Malta?
- What source of water other than rainfall do you use, if any?
- What type of nutrients and fertilisation products do you use throughout the year, if any? Are these applied according to a planned program?
- What pesticides do you use, if any? And are these applied according to a planned program or only after a disease or pest is observed?
- Do you count the number of buds you leave for each vine when pruning? If yes, how many buds do you usually leave?
- What price would you consider to be decent for your grapes?
- What is, in your opinion, the most important challenge you face at any point throughout the year with respect to the upkeep of vineyard/s?
- Who is most likely to be taking of your vineyard/s in ten years' time?
- Would you consider renting your field to a commercial wine company for a fixed price so that professional viticulturists will take care of it and the company will take the grapes in return?