Master Thesis

Silica Application as a Promising Approach for Control of Fungal Diseases for Grapevine *Vitis vinifera* L.

February 14, 2017

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Abstract

Silicon applications have the potential to substitute cost intensive and environmentally unfriendly fungicide treatments for grapevine *Vitis vinifera* L. An enormous amount of literature examines the benefits of silicon in improving overall crop productivity and health under biotic and abiotic stress for many agrarian cultures. Powdery and downy Mildew are the major fungal pathogens in grape growing, which cause immense damage every year. Previous studies tried different silicon components for the control of fungi for grapevine, but their results are contradictory. Therefore, this thesis tests the efficiency of silica soil amendments and foliar spray to control for mildew pathogens for grapevine cv. Grüner Veltliner in a field trial in Austria. Assessments of fungal infestations determined reduced rates of powdery mildew for silica treated plants. Silicon deposits in the leaves doubled for the silica foliar spray. Although the enrichment of the soil with silicon was high, there is no evidence of increased silicon uptake by the plants from the soil. Photosynthetic measurements revealed that intense spraying of conventional systemic fungicides reduced the photosynthetic activity of grapevine. Silica treatments are a potential substitute for the control of powdery mildew. Material cost is low, plant performance is not disturbed and silica would potentially fall within guidelines for organic winegrowers as a natural substance.

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1 Introduction

The history of European grape-growing can be divided into three periods. The first (before 1845) was characterized by the absence of major phytosanitary problems. This was followed by a troubled half century during which European grape crops were faced with the arrival of three major problems: (1) powdery mildew, (2) phylloxera and (3) downy mildew. The following years were characterized by a search for solutions for these problems and a period of intensive use of chemical protection lasting until the present (Gessler et al., 2011). The European grape species *Vitis vinifera,* mainly used for winemaking due to its unique characteristics, is propagated vegetative. Therefore, there was no possibility of a natural adaption to mildew pathogens and *Vitis vinifera* is highly susceptible. *Plasmopara viticola,* causing downy mildew, and *Uncinula necator,* responsible for powdery mildew, are endemic on wild Vitis species of North America. Many of those non-vinifera grape species display varying levels of resistance to fungal pathogens due to co-evolution (Gadoury et al., 2012). The cultivation of resistant grape species or interspecific hybrids is only of minor importance at present time. The principal barriers are market driven such as consumer acceptance of new varieties, unusual tastes and most often a perceived reduced quality of fruit and wine (Gessler et al., 2011).

Diseases caused by these fungal pathogens are among the major constraints of viticulture. Repeated fungicide treatments generate important economic losses, emergence of resistant pathogen populations and potential environmental impacts. In organic viticulture the use of copper for control of downy mildew has long-term consequences due to its accumulation in the soil, which is incompatible with organic farming's objective of environmental friendliness (Currie and Perry, 2007). Not only environmental issues force viticulturists to find alternative methods for the management of fungal plant pathogens, but also governmental restrictions are imposed. With the revision of plant protection products undertaken in the EU (Council Directive No 414/91), many conventional fungicides have been removed from the market (Gessler et al., 2011). The Commission Regulation of the European Union (EC) No 473/2002 amended Annex II specifies the conditions under which copper may be used and introduced limits on its use (The European Commission, 2002) which were confirmed in 2007 in the Council Regulation (EC) No. 834/2007 on organic production and labeling of organic products (The European Commission, 2007).

Dagosting et al. (2011) tested a total of 112 different treatments, including biocontrol agents, materials of animal origin, homeopathic preparations, inorganic materials, microbial extracts, natural derivatives, plant extracts, physical methods and synthetic materials and almost none of them resulted to be a good substitute of copper in terms of disease control effectiveness thus indicating the need for alternatives. Although deemed as nonessential nutrient for plants, silicon (Si) has been proposed as a viable alternative to conventional control techniques. In the past 20 years manifold scientific documentation gave evidence of the benefits of Si to crops and brought light into the Si-driven mechanism enhancing the productivity of a wide array of crops under stressed conditions (Tubana et al., 2016).

Silicon is the eighth most common element in the universe by mass, but very rarely occurs as the pure free element in the Earth's crust. It is widely distributed in dusts, sands, planetoids, and planets as various forms of silicon dioxide (silica) or silicates (Hull, 1999). Over 90% of the Earth's crust are composed of silicate minerals, making silicon the second most abundant element in the Earth's crust after oxygen. It adds up to 70% of the soil mass in the form of minerals and water-soluble silicic acid (H_4SiO_4), which is the fundamental building block of silica (Sakr, 2016). Silicon is used commercially, often with little processing of the natural minerals. Such use includes industrial construction with clays, silica sand, and stone. Silicate is used in cement, white ware ceramics and glass. Elemental silicon has a large impact on the modern world economy such as in the steel refining, aluminum-casting, and fine chemical industries. Very highly purified silicon used in semiconductor electronics is essential in modern technology. Silicon is the basis of the widely used synthetic polymers called silicones (Liang et al. 2015).

Moreover, silicon is an essential element in biology, although only traces are required by animals. Various sea sponges and microorganisms, such as diatoms and protozoa, secrete skeletal structures made of silica. Silica is deposited in many plant tissues, such as in the bark and wood of *Chrysobalanaceae* and the silica cells and silicified trichomes of *Cannabis sativa*, horsetails and many grasses. In higher plants, the silica phytoliths are rigid microscopic bodies occurring in the cell. Some plants, for example rice, need silicon for their growth (Liang et al. 2015). Silicon provides many benefits, such as improved resistance to pests and diseases, drought tolerance, salinity, heavy metals and high temperatures (Currie and Perry, 2007; Epstein, 1999). In the literature two hypotheses for silicon-enhanced resistance to fungal diseases have been proposed. The first one is associated with the higher deposits of silicon in the leaf so as to form a physical barrier to impede pathogen penetration. The second hypothesis is related to its biologically active role in the expression of natural defense mechanisms. While physical defense may partly explain the prophylactic effects of silicon, the biochemical defense is more accepted for explaining the protective role of silicon against many plant pathogens (Datnoff et al, 2007).

The next chapters focus on the abundance, occurrence and dynamics of Si in soil, the uptake, assimilation and Si-induced mechanism of resistance of plants and the specific fungal pathogens and their interactions with grapevine to give a conclusive picture of the silicon-plant-pathogens interactions.

1.1 **Silicon in Soil**

In rocks, the concentrations of silicon range from 23% (e.g. basalt) to 46.5% (e.g. orthoquartzite). Trance amounts of silicon are also in carbonaceous rocks (Monger and Kelly, 2002). The chemical weathering of silicate-containing minerals is the ultimate source of dissolved Si (as monosilicic acid, H_4SiO_4), which contributes to continental soil formation through linked biogeochemical reactions. Silicon release to the soil solution from weathering of silicate-containing minerals is rather slow and is governed by precipitation and neoformation of authigenic Si-constituents, Si adsorption/desorption on various solid phases, uptake and assimilation by vegetation and microorganisms, preservation of stable Si form in the profile, and addition from external atmospheric inputs. The largest inter-pool Si transfer takes place between biomass, biogenic silica from phytoliths and microorganism and soil solution (Tubana et al., 2016). The contribution of silicon to the soil solution from the atmosphere via wind-blown dust and phytolith particles is very small compared to soil-plant inputs (Tubana et al, 2015).

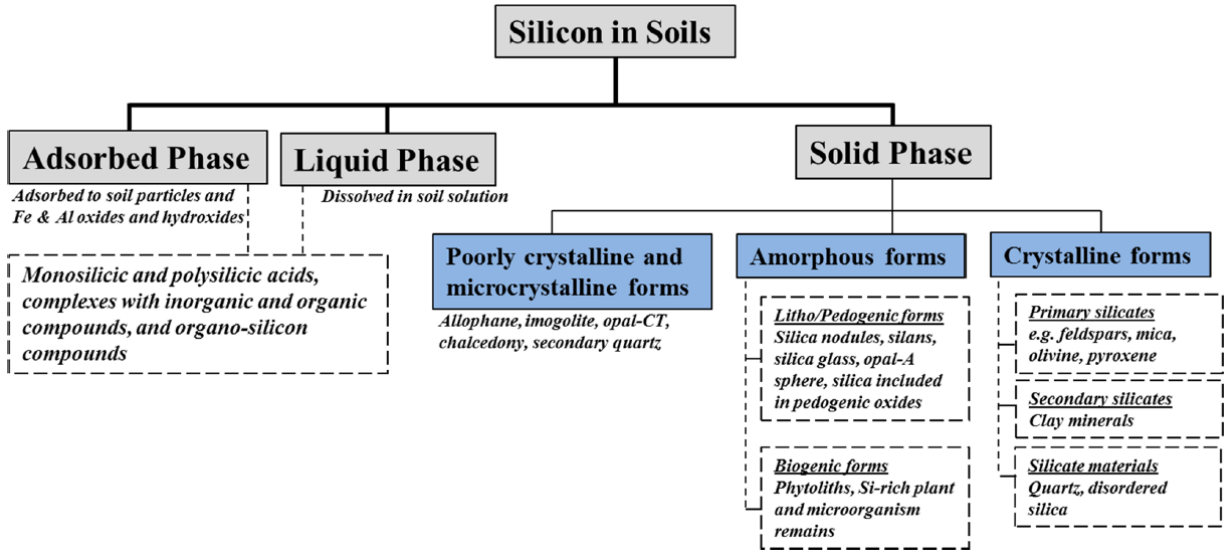

Figure 1: Different fractions of Si in soils (Tubana et al., 2016)

In soils, silicon is generally grouped into three different fractions (1) the liquid phase, (2) the adsorbed phase and (3) the solid phase, which are the key components of the silicon cycle in soil (Matichencov and Bocharnikova, 2001). Figure 1 shows the different fractions in the classification of silicon compounds in soils. The solid Si phase consists of poorly crystalline and microcrystalline, amorphous and crystalline forms of Si. The largest solid phase fraction of Si occurs in crystalline form consisting of primary and secondary silicates. Amorphous Si originates either from biogenic sources such as plant residues and remains of microorganisms or litho/pedogenic materials, which are Si complexes with Al, Fe, heavy metals and soil organic matter. The amount of amorphous Si ranges from less than 1,000 to 30,000 mg/kg on a total soil basis and effects the concentration of Si in soil solution (Tubana et al., 2016). The components of silicon in liquid and adsorbed phases are similar, with exception that those in liquid phase are dissolved in the soil

solution, whereas those that are adsorbed are held onto soil particles and Fe and Al oxides or hydroxides. A number of processes regulate the chemistry of silicon in the liquid phase: (1) dissolution of silicon contained in primary and secondary minerals, (2) absorption of H_4SiO_4 in the soil solution by the vegetation and microorganisms, (3) silicon adsorption on and desorption from various solid phases, (4) preservation of stable silicon in the soil profile (5) leaching and (6) addition such as by fertilization (Tubana et al., 2015).

Most soils are abundant in silicon, but certain soils contain low levels, especially of the plant-available form of silicon. These soils include Oxisols and Ultisols, which are characterized as highly weathered, leached, acidic and low in base saturation. Histosols, which contain high levels of organic matter and very low mineral content are also ranked as low Si soil. Additionally, soils composed of a large fraction of quartz sand and those that have been under long-term crop production typically have low plant-available silicon (Datnoff et al., 1997a). Crop cultivation can significantly alter the biogeochemical silica cycle and affects terrestrial silica mobilization and the availability of Si for the growth of plants and oceanic phytoplankton blooms (Liang et al., 2015). Based on data from the Food and Agriculture Organization of the United Nations (FAO) on world crop production, it was calculated that 210-224 million tons of plant-available Si are removed from the soil annually. This results in acceleration of mineral weathering, depolymerization of polysilicic acids, change of P, Al, heavy metals, Fe and Mn behavior, degradation of soil humic compounds, increased erosion, decreased microbial population and decreased plant Si nutrition. Si fertilization may be required on all soils except for unique soils with an abnormally high level of Si, such as recent volcanic soils. Silicon fertilizers increase the content of monosilicic acid in the soil (Matichenkov et al., 2001).

The application of a silicon-rich material influences the dynamics of different elements in the soil. Silicon is also added to soils with the application of manure and compost. The following direct effects of Si fertilizers on soil properties have been observed (Tubana et al, 2015):

(1) Optimization of phosphate fertilizer efficiency,
(2) increase in K fertilizer efficiency,
(3) decrease in Al toxicity,
(4) change in heavy metal mobility in the soil,
(5) initiation of soil mineral formation process,
(6) improvement in adsorption properties and water-air regime of soil.

1.1.1 Soluble and Available Silicon in Soils

Primary silicates and secondary mineral phases containing silica and biogenic silica to some extent dissolve in water to produce silicic acid. It is produced by a non-biological process called hydration involving water and quartz (Cooke et al., 2011). The reaction producing silicic acid from quartz can be written as:

$$\text{Quartz} + \text{Water} \rightarrow \text{Silicic acid}$$
$$SiO_2 + 2\ H_2O \rightarrow H_4SiO_4$$

Silicic acid concentration varies with soil type and is affected by its dissolution from soil minerals and its adsorption or resorption by the soil (Epstein, 1994). Extreme conditions including high temperatures and rainfall increase the release of silicic acid, explaining why most weathered soils in the tropics are silicon-deficient (Cooke at al., 2011).

Silicic acid (H_4SiO_4) is the only form of Si present in soil solution, whereas the measured concentrations range between 0.1 – 0.6 mM (Epstein, 1994), which is much less than that in saturated silicic acid solution and is mainly controlled by the pH-dependent absorption-desorption processes on sesquioxides (Liang et al., 2015). Available Si in soils refers to an amount of Si that can be taken up by plants during the growing season and is considered an index of Si-supplying capacity in soil. However, in silicic acid-saturated soil solution the monosilicic acid polymerizes into polymeric acid, which is in a dynamic equilibrium with amorphous and crystalline silicates, exchangeable silicates and sesquioxides. Therefore, parts of silicate components that can be easily converted into silicic acids such as polymerized silicic acid, exchangeable silicates and part of colloidal silicates also count to available Si (Liang et al., 2015).

The main factors influencing soil Si availability or Si-supplying power include types of soil and parent material, historical land-use change, soil pH, soil texture, soil redox potential, organic matter, temperature and accompanying ions (Liang et al., 2015). Moreover, the results of Biyutskii et al. (2016) highlight the importance of earthworms in plant acquisition and biogeochemistry of Si. Earthworms can increase mobility and bioavailability of silicon in soils.

1.2 Silicon in Plants

As other plants grapevines require three categories of resources to grow and produce fruit: (1) carbon, (2) water and (3) mineral nutrients. Exposed to suboptimal conditions abiotic and biotic stresses can be limiting to one or several resources to the plant. Abiotic stresses include overcast or too bright sky, heat or cold, water surplus or deficit and nutrient deficiency. Pests and disease attacks rank among biotic stresses. Grapevines share their living quarters with a wide range of other organisms, mainly arthropods and microorganisms, and in addition to some nematodes, birds, mammals and plants. Although the majority of these do not harm grapes, some organisms compete with the vines for resources or make a living feeding on various grapevine structures, which make them pests or pathogens (Keller, 2010). Although a certain level of stress will improve fruit quality in the vineyard, stresses adversely affect plant growth, development, or productivity. (Bauer et al., 2015).

Although not traditionally thought of as an element essential to the life cycle of plants, with the exception of the early-diverging *Equisetaceae*, Si is found in plants at concentrations from 1 to 100 g/kg which is equivalent to or even exceeding several macronutrients (Epstein, 1994). For plant nutrition silicon has not been considered as an essential element, according to the classical definition of essentiality (Arno and Stout, 1939), but it is regarded as one of the most beneficial elements that increases plant resistance against abiotic and biotic stresses. It has been shown to improve plant cell wall strength and structural integrity, improve drought and frost resistance, decrease lodging potential (Currie and Perry, 2007), and boost the plant's natural pest and disease fighting systems (Datnoff, 2007). Silicon has also been shown to improve plant vigor and physiology by improving root mass and density, and increasing above ground plant biomass and crop yields (Epstein, 2009b). In 2013, the American Association for Plant Food Control Officials (AAPFCO), the regulatory body that governs the labeling of fertilizers in the USA, recognized silicon as a beneficial substance that can now be sold as a fertilizer across the USA (Datnoff et al., 2015).

Silicic acid is the only known precursor of silicon compounds in biota, and plants take up aqueous, uncharged silicic acid through their roots when the pH-value of the soil solution is below 9 (Ma and Yamaji, 2006). The ability of plants to accumulate Si varies greatly between species. Silicon accumulation has been found to a greater extent, but not exclusively, in monocotyledonous plants. Plants of the families *Poaceae*, *Equisaetaceae* and *Cyperaceae* show high Si-accumulation whereas different parts of the same plant can show large differences in Si-content. Silicon concentration of shoots typically tend to decline in the order

liverworts > horsetail > clubmosses > mosses > angiosperms > gymnosperms > ferns

(Currie & Perry, 2007). Its uptake is passive for dicotyledons and largely determined by transpiration rate and is transported in the xylem. Therefore, silicon accumulates in higher amounts in mature leaves than in young ones (Ma and Takahashi, 2002). The absorption of silicic acid takes place at the lateral roots also via active or rejective mechanisms (Tubana et al. 2015).

An active mechanism corresponds to a silicon uptake in larger quantity than predicted by simple mass flow, while passive Si uptake is directly proportional to mass flow. Rejective uptake is characterized by low Si uptake by plants implying H_4SiO_4 accumulation in soil solution (Cornelis et al., 2011).

Two different silicon transporters have been identified in the roots of rice, a high silicic acid accumulating species. Such extreme accumulators contain 10 to 100g/kg Si in dry weight, and most are monocotyledons, such as wheat, sugarcane, rice and barley. Intermediate Si accumulators contain between 5 to 10g/kg dry weight and dicots plants with less than 5g/kg Si in dry matter are classified as low Si accumulators (Datnoff et al., 2015).

Silicic acid saturates at 1.67 mM and then becomes highly polymerized, resulting in the deposition of solid, amorphous, hydrated silica. Silicon can be deposited in any plant part, within or between cells or as part of the cell wall, with discrete silica bodies known as phytoliths which record shapes of the cellular and intercellular spaces that they fill. Once deposited, they are immobile and cannot be translocated to new growing leaves. Following plant senescence, much plant silicon dissolves in the soil solution and either cycles through biota or is leached into waterways. In some systems, most of the silicon entering streams has passed through the biogenic silica pool. However, some phytoliths can be preserved for long periods, although amorphous silica has a higher solubility than does quartz which is crystalline silica (Cooke et al, 2011).

Plants deprived of Si are often weaker structurally and more prone to abnormalities of growth, development and reproduction. It is the only nutrient which is not detrimental when collected in excess (Epstein, 1994). The mechanisms which are responsible for relieving stresses remain partly unclear and are thought to act in the soil, at the root surface and within plants at shoots and roots (Van Bockhaven et al, 2013). As mentioned previously, the mechanical barrier formed from Si polymerization below the cuticle and in the cell walls was the first proposed hypothesis to explain how Si reduces or impedes fungal penetration (Ma et al., 2004). However, new insights suggest Si effects on plant resistance may also occur through mediated host plant resistance mechanisms against pathogen infection (Rodrigues et al., 2015).

In such a mechanism an R gene of the plant forms products, such as proteins, or activates a defense mechanism that transfers resistance to specific plant pathogens. Silicon has been shown to up- and downregulate certain genes and their defensive products in a number of host-pathogen interactions. Activities of pathogenesis-related proteins, peroxidase, polyphenol oxidase and chitinase were significantly stimulated by Si in cucumber *Cucumis sativus* (Tubana et al., 2015). Fauteux et al. (2005) suggested that Si might act as a potentiator of plant defense response or as an activator of specific signaling proteins that interact with several key components of plant stress signaling systems, leading to induced resistance against pathogenic fungi. Although the molecular mechanism of how such priming is associated with Si are not well understood, a growing body of research suggests that Si may be influencing plants' endogenous defensive hormone balance (Rodriques et al., 2015). Higher levels of salicylic acid, jasmonic acid

and ethylene have been reported to be induced by Si supplements in a number of host-pathogen interactions. Clearly more research is warranted to determine how Si potentiates host plant resistance against both biotic and abiotic stress (Tubana et al., 2015).

1.3 **Major Fungal Pathogens of Grapevine**

Grapevine species are prone to several diseases, fungi being the major pathogens compromising its cultivation and economic profit around the world. Knowledge of the complexity of mechanisms responsible for resistance to fungus infection is necessary to develop strategies which will improve the grapevine's resistance (Bauer et al., 2015).

1.3.1 Powdery Mildew

Uncinula necator (syn. *Erysiphe necator*) is a fungus that causes grapevine powdery mildew, also termed Oidium. It is the most widespread and most consistently damaging pathogen which is parasitic on genera within the *Vitaceae*. The most economically important host is grapevine (*Vitis*), particularly the European grape, *Vitis vinifera*, which is highly susceptible. The fungus originated in North America and spread through Europe in the 1840s at a time where little was known about germ theory (Gadoury et al., 2012).

Uncinula necator infects all green tissue on the grapevine, including leaves and young berries. Ascospores colonies are most commonly found on the lower surface of the leaves and may be accompanied by a similarly shaped chlorotic spot on the upper surface. Severely affected leaves usually senesce, develop necrotic blotches and fall prematurely. Inflorescences and berries are most susceptible when young and can become completely coated with whitish mildew. Powdery mildew causes crop loss and poor wine quality if untreated (Bauer et al., 2015).

This fungus requires only 40% relative humidity to germinate, a threshold that is easily reached on the lower surface of transpiring leaves, even if the surrounding air is much drier. The optimum is at 85% humidity and 25°C, but heavy rain and temperatures below 10 and over 31°C limit the development. Mild rainfall seems to benefit by enhancing spore dispersal. Spores germinate on the surface of plant organs, invade the cuticle and cell walls and rapidly establish haustoria inside the epidermis cell. Like all biotrophic pathogens, *U. necator* needs living host plants for assimilate supply. It suppresses the defense responses in susceptible cultivars and acts as another sink. Infected leaves have higher concentration of sugars especially hexoses due to import of sucrose from uninfected plant parts and subsequent breakdown by invertase in the cell walls. An injection of cytokinin from the pathogen induces invertase activity and also involves amino acid imports. Photosynthesis and starch storage will decrease in infected leaves. This powerful extra sink alters assimilates partitioning in the vine at the expense of other sinks such as fruit, roots and storage reserves (Keller, 2010).

Unlike American *Vitis* species, which are relatively resistant to the fungus, European *Vitis vinifera* L. cultivars are readily infected because they did not coevolve with the pathogen and produce lower amounts of PR proteins. Within European cultivars susceptibility varies, with Chardonnay and Cabernet Sauvignon being among the most susceptible cultivars (Keller, 2010). Even though

stilbene phytoalexins are also effective against *Uncinula necator,* infections do not normally trigger their production. One explanation could be that the fungus avoids cell damage so as not to threaten its own survival. The resistant American *Vitis* species accumulate stilbenes in response to infections. Also flavonols, which accumulate in the epidermis, and cuticular wax may be involved in Vitis *vinifera* resistance against *Uncinula necator* (Keller, 2010). Flavonol production is strongly reduced by high soil nitrogen availability and high plant N status makes vines more susceptible to colonization by powdery mildew. An additional resistance mechanism may be vitrification of penetrating mycelium by the localized accumulation of silicates in the cell walls (Blaich and Wind, 1989).

Figure 2: Symptoms of powdery mildew, left: fully infested grape cluster (own picture), right: spots of powdery mildew on the adaxial side of the leaf (www.rebschutzdienst.at)

1.3.2 Downy Mildew

Although usually regarded as a fungus because it looks like one and produces spores, the causal agent *Plasmopora viticola* is in fact more closely related to certain algae, kelps and diatoms with which they are placed in the kingdom of Protista. In contrast to fungi, its cell walls contain cellulose instead of chitin and its cell nuclei are diploid, not haploid. It belongs to the class of Oomycetes and is not related to the powdery mildew fungus. (Gessler et al., 2011)

Plasmopora viticola also termed Peronospora can infest all green parts of the plant but usually colonizes young leaves or young berries by penetrating through the stomata. The spores can germinate at greater than 95% relative humidity in shady conditions especially with frequent rainfall and temperatures between 20 and 25°C. The mycelium develops an intercellular network in the leaf mesophyll and creates haustoria to feed from these cells. The first symptoms appear on the adaxial side of leaves as yellow or in some cultivars red oily spots, which spread and later

become angular necrotic patches. On the abaxial leaf surface the typical whitish downy symptoms arise from the sporulation of the pathogen through the stomata (Keller, 2010). The invading pathogen prevents the stomata from closing at night. The unrestrained water deficit leads to water loss and wilting of infected leaves. *Plasmopora viticola* does not stimulate sugar accumulation in infected leaves like *Uncinula necator,* but an infection leads to a reduction in photosynthesis and the shedding of severely damaged leaves. This can have negative effects on yield formation and fruit ripening as for the storage of reserves. Infected shoot tips, tendrils, petiols and inflorescences often become necrotic and are abscised. The young grape berries get covered with a grayish felt (Gessler et al., 2011).

While *Vitis vinifera* is highly susceptible, American *Vitis* species, which have coevolved with the pathogen, are partly or fully resistant to downy mildew, and some Asian species also show partial resistance. Resistant species defend themselves against the fungal pathogen by secreting callose that plugs their stomata and coats the pathogens spores. This stops mycelial growth, reduces water loss from the leaves and stilbenes are upregulated. High plant N status seems to compromise the leaves' ability to produce stilbenes and leads to higher vulnerability to infection. Garibaldi et al. (2012) have found that Si and an increased electrical conductivity lead to a reduction of downy mildew infections of soilless grown lettuce.

Figure 3: Symptoms of downy mildew, left: infested and uninfested berries, right: a necrotic spot on the abaxial side of the leaf surrounded by a downy mycelium (own pictures)

1.4 **Defense and Resistance of Grapevine**

A prospective pathogen that attempts to penetrate the epidermis first has to overcome the cuticle and thick outer cell walls on the leaves. The thickness of the cuticle and the outer cell wall of different *Vitis* cultivars determine their susceptibility to powdery mildew (Heintz and Blaich, 1989). Access points for pathogens are wounds caused by herbivore, birds, arthropods or mechanical damage. During anthesis exposed surfaces provide ideal sites for pathogen invasion and therefore special attention for plant protection has to be paid during flowering. Plants respond to physical damage by mechanisms that aim to heal wounds and prevent pathogen invasion. Deposition of callose, lignin glycoproteins and phenolics strengthen the cell wall and the production of so-called pathogenesis-related (PR) proteins such as chitinases and glucanases increase the defense mechanism (Gessler et al., 2011).

If defense responses are unsuccessful and pathogens penetrate into the tissues, plants have evolved a broad range of strategies to resists fungal infections. These strategies are either constitutive or induced. Constitutive resistance strategies are passive and are present regardless of an infection. They include physical barriers such as cell walls, the cuticle and chemicals with antimicrobial activity like phenolics, which are generally accumulated in the cell vacuoles (Keller, 2010).

Induced strategies are actively initiated in response to pathogen invasion and specifically target pathogens that have overcome the constitutive barriers. The production of reactive oxygen species and antimicrobial compounds such as proteins and phytoalexins starts. The fortification of cell walls with lignin, suberin or the incorporation of callose, proteins or silicon are part of the induced strategies. Active defense is usually restricted to the site of invasion as only infected and neighboring cells accumulate the antimicrobial chemicals to concentrations to restrict the spreading of the pathogen (Keller, 2010; Gessler et al., 2011). The first hypothesis of silicon-enhanced resistance is associated with silicon deposits in the cell walls and below the cuticle which act as an addition physical border (Sakr, 2016).

Plants have special receptor proteins that can recognize invading pathogens by some of the microbial enzymes or complex carbohydrates. They are able to interpret the breakdown products of their own cuticle and cell walls as signals of the intruder. These compounds are collectively termed elicitors. The defense response results from activation of various biochemical pathways by a series of signaling cascades that are triggered by the detection of a pathogen. Within minutes of an attempted infection by a foreign invader, there is a rapid rise in reactive oxygen species in the apoplast (Apel and Hirt, 2004). The surrounding cells mount structural barriers and produce PR-proteins which degrade chitin and glucans, which are important components of the cell walls of fungi (Keller, 2010).

Secondary signaling molecules, including salicylic acid, jasmonic acid and ethylene then augment the early defense response and may even activate defenses in distant healthy tissues and act systemically (Heil and Ton, 2008). In some instances, these secondary signals and H_20_2 make

infected and surrounding cells to commit suicide in a process termed hypersensitive response. This limits food supply to the pathogen and may kill it. Although, this strategy is indeed useful in fighting off biotrophs such as *Unicator. neca*tor and *Plasmopora. viticola*, the susceptibility to necrotrophs rises. Necrotrophs such as *Botrytis cinerea* grow on dead tissues and can exploit the plant's defense response by promoting tissue senescence. (Keller, 2010)

If the pathogen could penetrate into the tissue, the vine activates a second line of defense after several hours. This biochemical defense includes accumulation of antimicrobial compounds, including phytoalexins and PR proteins. In response to xylem-invading fungal pathogens, the accumulation of elemental sulfur in the vessel walls and xylem parenchyma cells is expedited (Gessler et al., 2011).

1.5 **Research Objective**

The aim of this thesis is to test the efficiency of silicon applications to control for downy and powdery mildew in grapevine *V. vinifera* L. cv. Grüner Veltliner in a field trial. In the literature two hypotheses for silicon-enhanced resistance to fungal diseases have been proposed: (1) Increased levels of silicon deposits in the plant act as physical barriers and (2) the upregulation of natural defense mechanism which actively fight off fungal pathogens.

Previous studies have shown that the supplement of silicon to grapevine increased the maximum yield and potential photochemical efficiency of the photochemical reactions in photosystem II (Qin et al., 2016). Ling et al. (2016) state that silicon might play an important role in protecting photosynthetic machinery from damage and improving the salt-tolerance of the grapevine by increasing the concentration of soluble sugars and starch.

On potted plants root-feeding at 1.7mM silicon solution had no effect on fungal disease severity, but foliar sprays at 17mM Si substantially reduced the number of mildew colonies that developed in inoculated grapevine leaves. Hyphae did not develop in areas where thick Si deposits were present on the leaf surface (Bowen et al, 1992). Reynolds et al. (1995) showed that potassium silicate sprays reduced the incidence of powdery mildew in two of three years. The study concluded that grape berries may utilize endogenous Si to help fight diseases. Furthermore, exogenously applied silicates may act to augment the activity of their endogenous counterparts. Appropriate application intervals and concentrations will increase the effectiveness of silicon sprays.

Klaus et al. (1990) performed a Si-fertilizer trial in a vineyard with grapevine cv. Müller-Thurgau and Silvaner. Vines were fertilized with 2.5 and 5 t/ha of calcium silicate over four years before starting measurements. Minor Si accumulation in the tested leaves could be determined. However, Leusch (1986) indicates that the fertilization with calcium silicate does not always lead to an increased amount of silicic acid due to a rise in pH and therefore a reduced solubility. The

authors note that the conversion from calcium silicate into silicic acid performed unsatisfactory and may have been the reason for the insignificant uptake.

Lafos (1995) states a 10% reduction of powdery mildew due to Si fertilization in the greenhouse but emphasizes large differences between cultivars. Blaich (1997) showed significant varietal differences only for cv. Regent, an inter-specific hybrid grape variety, which accumulated about 20% more Si.

Blaich et al. (1997) deny the efficiency of silica sprays against fungal infections. The results from Blaich et al. (1998) show silica to be essential for a normal powdery mildew resistance, but provide evidence that Oidium susceptibility of cultivars cannot be overcome by supplementary silica fertilization in the field. Furthermore, they state that the Si content of most soil solutions are far above the minimal requirements of grapevine (Blaich et al, 1998). However, continuous cropping of land, natural weathering, or inherently deficient soils can be causes of deficiency (Tubana et al., 2016) and will become even more problematic in the future. Although some studies contradict each other, most of the studies have revealed benefits of silicon fertilization and foliar sprays for grapevine. Silicon seems to have potential as an alternative spray material to fungi control and impresses with low material cost, lower risk of off-flavors like H_2S in wines and its potential acceptability in guidelines for organic winegrowers as a natural substance (Tubana et al., 2016).

Since many of the previous studies were performed in the green house and used different silicon solution such as potassium silicate or calcium silicate, this study was performed as a field trial. For the fertilization and the foliar sprays silica is used to avoid any interfering effects of binding partner like potassium or calcium. Assessments of fungal pathogens were used to monitor the status of infestations of the different treatments. Soil samples were analyzed to determine if Si amendments enrich the soil in the top and subsoil layer. Foliar samples were analyzed for their Si concentrations to assess the effect of the treatments on Si allocation to leaves. Moreover, measurements of the photosynthetic performance were taken to detect stress factors. At the end of the growing season the fruit quality of the different treatments was compared.

In this study the following hypothesis were tested:

H_1: Silicon treatment can partly substitute for fungicides while maintaining a similar level of fungal symptoms.
H_2: Silicon fractions in the soil are enriched due to Si fertilization.
H_3: Si-treated plants show higher levels of silicon in the leaves than untreated plants.
H_4: Si-treated plants are less stressed and show higher photosynthetic activity.
H_5: Grape clusters of Si-treated plants show better quality than grape clusters of untreated plants.

2 Material & Methods

2.1 Experimental Design

The field trial was situated in Krems Landersdorf at a vineyard of the School of Viticulture and Horticulture in Krems, Austria and was supported by Ing. Christoph Gabler and Ing. Erhard Kührer. For each treatment 48 plants of *Vitis vinifera* cv. Grüner Veltliner (scion: SO4) were used and divided into four groups of 12 plants. The vineyard was planted in 2012 with a distance of 3x1m (Figure 4).

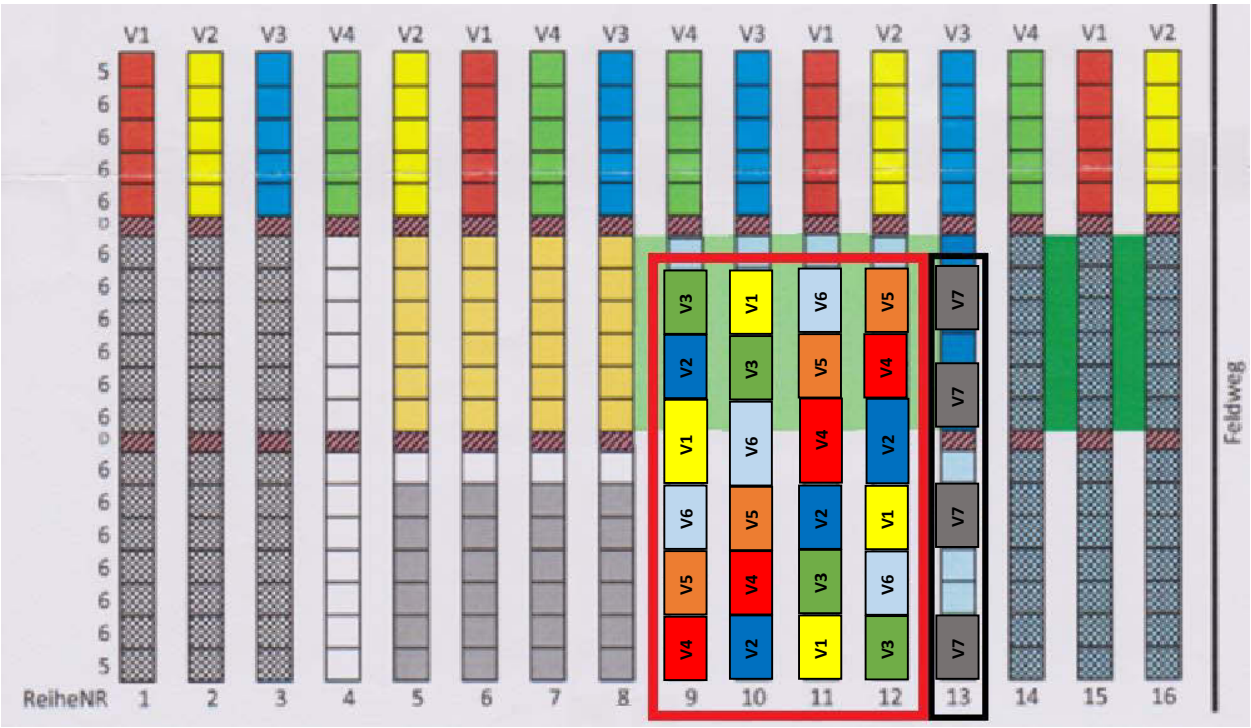

Figure 4: Experimental design, V1: Amorphous Silicon Soil Amendment (yellow), V2: Amorphous Silicon Foliar Spray (blue), V3: Amorphous Silicon Combination V1 + V2 (green), V4: Equisetum Plus Spray (red), V6: Control Group Water Spray (light blue), V7: Control Group Common Plant Protection (grey), colored blocks consisted of 12 plants, total number of plants per treatment were 48

Amorphous silica was either applied to the soil as a fertilizer (V1) or sprayed as foliar spray to the canopy (V2). For treatment V3 a combination of Si-fertilization and foliar spray was used. In treatment V4 a horsetail extract, which has already been used in organic viticulture was applied as foliar spray. The control groups V5 and V6 received water sprayed on leaves and soil irrigation with water, respectively. Treatment V7 served as a comparison to common plant protection.

2.2 **Soil Characteristics**

Before starting the experiment soils of different vineyards were analyzed to ensure low plant-available and amorphous silicon in the soil. The vineyard at Krems, Landersdorf is low in both silicon fractions. Table 1 shows the analysis of silicon in the soils of the experimental vineyard. Plant-available (i.e. $CaCl_2$-extractable) Si amounted to 0.126 mM in the topsoil and 0.118 mM in the subsoil which compares to a typical range between 0.029 – 0.175 mM plant-available silicon (Sakr, 2016), indicating a medium available Si status of the experimental soil. Similarly, also for the amorphous fraction (i.e., NaOH-extractable) of silica (1.25 g/kg in the top and 1.37 g/kg in the subsoil) falls in the lower range compared to the typical range of 1,000 to 30,000 mg/kg as reported by Tubana et al. (2016).

Table 1: Silicon analysis of the vineyard in Krems, Landersdorf, soil samples were taken on March 18, topsoil ranges from 0-30 cm, subsoil ranges 30-60 cm, plant-available silicon was analyzed with a $CaCl_2$-extraction modified from Haysom and Chapman, 1975 and Liang et al., 2015, amorphous silicon was extracted with a NaOH-solution modified from Georgiadis et al., 2015

Soil Analysis	Plant-available Silicon (in mM)	Amorphous Silicon (in mg/kg)
Topsoil	0.126	1,250
Subsoil	0.118	1,370

Table 2 provides additional information about the soil characteristics of the vineyard. According to its texture composition of around 100 g/kg sand, 700 g/kg silt and 200 g/kg clay it can be classified as loess soil, an aeolian sediment formed by the accumulation of wind-blown silt (Miller et al., 1990). A thick blackish mineral surface layer that is rich in organic matter and the parent material of mostly aeolian and reworked aeolian sediments indicate the classification of a Chernozems soil. This soil is typical for this region and develops in a continental climate (FAO, 2015). The carbon-to-nitrogen ratio at a medium level for a cultivated Chernozem soil.

Table 2: Characteristics of the experimental soil in Krems, Landersdorf, analysis was performed according to Blum et al. (1996)

Soil	pH	Sand	Silt	Clay	C/N ratio	Organic Carbon	Carbonate Content	Nitrogen
Topsoil	7.43	100 g/kg	672 g/kg	228 g/kg	13.8	19.3 g/kg	184.9 g/kg	1.4 g/kg
Subsoil	7.55	89 g/kg	758 g/kg	153 g/kg	16.4	16.4 g/kg	192.1 g/kg	1.0 g/kg

2.3 Treatments

[V1] **Amorphous Silicon – Soil Amendment**
LUDOX TM-50 Colloidal Silica was applied to the soil with a watering pot in 6 portions during the growing season. For an easier application and to avoid drain of the fertilizer a pouring ring around the vine with a diameter of 40cm were installed. A total amount of 5 t/ha LUDOX TM-50 Colloidal Silica were applied (Table 3). Taking into account that this is a 50% wt. suspension in water, this corresponds to a total amount of 2.5 t/ha of silica.

Amount of application for 48 plants:

Table 3: Detailed information for the soil amendment with LUDOX TM-50 Colloidal Silica for the treatment V1 and V3. The same amount of water was used for the control group V5, the BBCH-code identifies the phenological stages of the grapevine

Date	BBCH	Product	Amount	Concentration	Water	M SiO_2 per Plant
19-May	17	LUDOX TM-50 Colloidal Silica	8.0 l	4.20%	192 l	93.0
7-Jun	57	LUDOX TM-50 Colloidal Silica	3.2 l	1.70%	192 l	37.2
28-Jun	73	LUDOX TM-50 Colloidal Silica	3.2 l	1.70%	192 l	37.2
12-Jul	77	LUDOX TM-50 Colloidal Silica	3.2 l	1.70%	192 l	37.2
29-Jul	81	LUDOX TM-50 Colloidal Silica	3.2 l	1.70%	192 l	37.2
17-Aug	83	LUDOX TM-50 Colloidal Silica	3.2 l	1.70%	192 l	37.2

[V2] **Amorphous Silicon – Foliar Spray**
The first two applications were sprayed at a concentration of 1% of LUDOX TM-50 colloidal silica. After the first assessment of fungal diseases the amount was increased to a concentration of 2% to gain better results (Table 4).

Amount of application for 48 plants:

Table 4: Detailed information of the foliar spray with LUDOX TM-50 Colloidal Silica for the treatment V2 and V3. The same amount of water was used for the control group V6, the BBCH-code identifies the phenological stages of the grapevine

Date	BBCH	Product	Amount	Concentration	Water	mM SiO_2 per Plant
19-May	17	LUDOX TM-50 Colloidal Silica	50ml	1.00%	5 l	12.1
7-Jun	57	LUDOX TM-50 Colloidal Silica	60ml	1.00%	6 l	14.5
28-Jun	73	LUDOX TM-50 Colloidal Silica	160ml	2.00%	8 l	38.8
12-Jul	77	LUDOX TM-50 Colloidal Silica	160ml	2.00%	8 l	38.8
29-Jul	81	LUDOX TM-50 Colloidal Silica	160ml	2.00%	8 l	38.8
17-Aug	83	LUDOX TM-50 Colloidal Silica	200ml	2.00%	10 l	48.5

[V3] **Amorphous Silicon – Soil Amendment + Foliar Spray**
This treatment was a combination of V1 and V2 and exactly the same amount of LUDOX TM-50 Colloidal Silica was brought out for the soil amendment from V1 and the foliar spray from V2 (Tables 3 and 4).

[V4] **Equisetum Plus – Foliar Spray**
The first two applications were sprayed at a concentration of 1% of Equisetum Plus. After the first assessment of fungal diseases the amount was increased to a concentration of 2% to gain better results (Table 6).

Amount of application for 48 plants:

Table 5: Detailed information of the foliar spray with Equisetum Plus for the treatment V4, the BBCH-code identifies the phenological stages of the grapevine

Date	BBCH	Product	Amount	Concentration	Water
19-May	17	Equisetum Plus	50ml	1.00%	5 l
7-Jun	57	Equisetum Plus	60ml	1.00%	6 l
28-Jun	73	Equisetum Plus	160ml	2.00%	8 l
12-Jul	77	Equisetum Plus	160ml	2.00%	8 l
29-Jul	81	Equisetum Plus	160ml	2.00%	8 l
17-Aug	83	Equisetum Plus	200ml	2.00%	10 l

[V5] **Control group – Watered**
For this control group the same amount of water was brought out as for the treatment V1. The product LUDOX TM-50 Colloidal Silica was not added (Table 3).

[V6] **Control group – Water Spray**
For this control group the same amount of water was sprayed as for treatment V2. The product LUDOX TM-50 Colloidal Silica was not added (Table 4).

[V7] **Common Plant Protection**

This treatment acted as a comparison to common conventional spraying. Different systemic and non-systemic fungicides were applied to avoid emergence of resistant pathogen populations.

Amount of application for 48 plants:

Table 6: Detailed information of the common plant protection treatment (V7), the BBCH-code identifies the phenological stages of the grapevine

Date	BBCH	Product	Amount	Concentration	Water
19-May	17	Polyram WG	9.6 g	0.17%	5.8 l
		Kumulus	55.2 g	0.95%	
		Topas	1.8 ml	0.03%	
1-Jun	19	Polyram WG	9.6 g	0.13%	7.2 l
		Prosper	6 ml	0.08%	
16-Jun	68	Veriphos	36 ml	0.30%	12 l
		Delan 700 WG	4.8 g	0.04%	
		Luna Experience	4.5 ml	0.04%	
24-Jun	71	Aktuan Gold	15 g	0.09%	16.8 l
		Legend Power	16.8 ml	0.10%	
5-Jul	75	Enervin	36 g	0.19%	19.2 l
		Kumar	60 g	0.31%	
19-Jul	79	Aktuan Gold	18 g	0.09%	19.2 l
		Kumar	60 g	0.31%	
2-Aug	81	Cuprozin	19.2 g	0.10%	19.2 l
		Veriphos	48 ml	0.25%	
		Kumar	60 g	0.31%	

2.4 Plant Protection

Additionally, conventional spraying as foliar spray was applied to all treatments and controls except for the common plant protection (V7) (Table 6). This basic plant protection was used depending on weather conditions and infection risk of fungal pathogens. It was planned to implement silicon applications into an organic viticulture plant protection plan, which uses mainly copper and sulfur. Due to high infection risk of *Plasmopora viticola,* Aktuan Gold, a systemic fungicide, was used once to keep downy mildew at bay.

Amount of basic plant protection applications for 48 plants:

Table 7: Detailed information of the basic plant protection for all treatments.

Date	BBCH	Product	Amount	Concentration	Water
16-Jun	68	Cuprozin Progress (Copper)	26ml	0.40%	6.5 l
		Stulln (Sulfur)	45.5g	0.70%	
24-Jun	73	Aktuan Gold	40ml	0.40%	10 l
1-Aug	81	Cuprozin Progress (Copper)	50ml	0.40%	12 l
		Stulln (Sulfur)	85g	0.70%	
15-Aug	85	Cuprozin Progress (Copper)	50ml	0.40%	12 l
		Stulln (Sulfur)	85g	0.70%	

2.5 Time Table

Figure 5 gives an overview of all actions during the field experiment. Silicon applications of soil amendment and foliar spray started in week 20 in the mid of May and ended at week 33 in the mid of August. Soil samples were taken right before soil amendment, after three applications of silicon and after 6 applications. Leaf samples were taken after each two applications of silicon. The analysis of photosynthesis was measured 5 times over the vegetation period. Fruit quality was measured at harvest time.

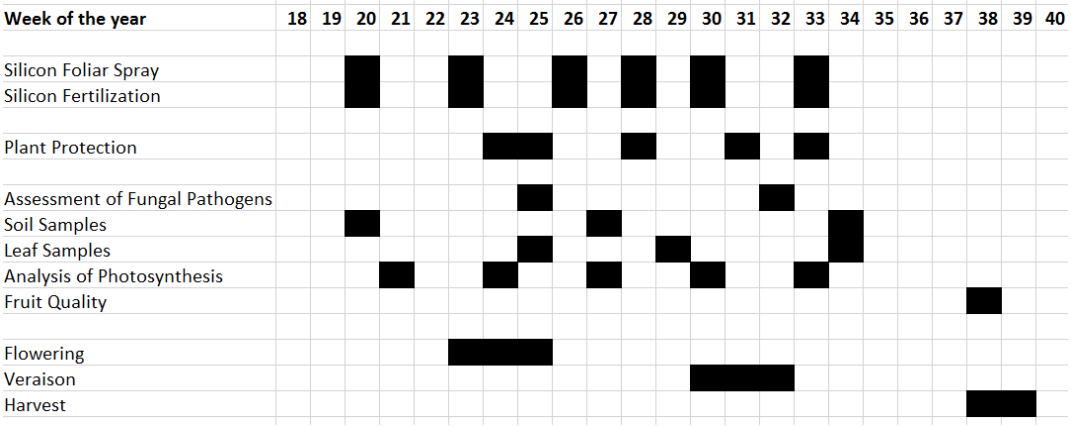

Figure 5: Time table of all applications and measurements

2.6 Weather Data

The vegetation period in 2016 was dominated by frequent rainfalls. June and July had three times higher precipitation than in the year before (Tables 7 and 8). Average relative humidity was in these months also higher in 2016 compared to 2015. These are two important factors which favor spreading and infections of fungal pathogens and presented viticulturists with a challenge for plant protection.

A detailed overview from Vitimeteo, a forecast system for plant protection in viticulture, of daily rainfalls and fungal infections can be found in the Appendix.

Table 8: Weather data 2015 from Adcon Telmetry Live Data, Krems Landersdorf

Weather Data 2015	April	May	June	July	August	September
Average Temperature (°C)	10.8	14.9	19.4	23.5	23.0	15.3
Minimum Temperature (°C)	-2.7	5.6	10.6	9.0	9.3	3.6
Maximum Temperature (°C)	25.9	33.7	38.5	38.0	38.0	35.5
Precipitation (mm)	8.8	64.2	23.8	32.2	61.6	76.0
Average Relative Humidity (%)	60	73	67	59	64	67
Minimum Relative Humidity (%)	20	26	22	20	17	25
Maximum Relative Humidity (%)	97	100	99	100	100	100

Table 9: Weather data 2016 from Adcon Telmetry Live Data, Krems Landersdorf

Weather Data 2015	April	May	June	July	August	September
Average Temperature (°C)	10.4	14.9	19.3	21.3	19.4	17.5
Minimum Temperature (°C)	-2.3	4.0	10.3	11.1	7.3	4.3
Maximum Temperature (°C)	23.6	27.4	32.8	35.1	31.6	30.9
Precipitation (mm)	39.4	70.8	70.4	96.0	45.8	19.6
Average Relative Humidity (%)	69	71	73	71	73	74
Minimum Relative Humidity (%)	24	35	36	29	25	34
Maximum Relative Humidity (%)	100	100	98	100	100	100

2.7 **Measurements**

2.7.1 Assessment of Fungal Diseases

Infections of Powdery Mildew (Uncinula necator) and Downy Mildew (Plasmopara viticola) were documented at two times during the period according to EPPO standards PP 1/31(3) *Plasmopara viticola* and PP 1/4(4) *Uncinula necator*, which can be found in the Appendix. The first time was on June 24 where only Downy Mildew was assessed due to a lack of symptoms from Powdery Mildew. The second assessment was on August 11 where both fungal diseases were monitored. Figure 8 shows the percentage of infected leaf surface as a guideline for assessing fungal infections.

To assess percentage of leaf surface and affected bunch area, the following scale was used to class-divide the different levels of infection:

1 = no disease
2 = <5%
3 = 5-10%
4 = 10-25%
5 = 25-50%
6 = 50-75%
7 = >75%.

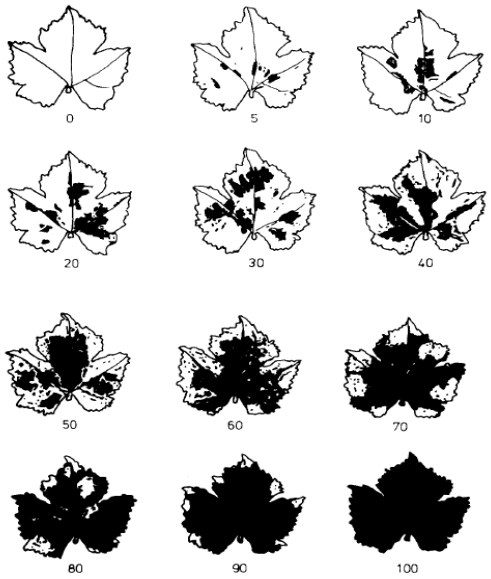

Figure 6: Overview of the percentage of abaxial leaf surface affected by downy mildew (EPPO standards PP 1/31(3))

Out of these classes two performance indicators were calculated:

n ..... number of observation
i ..... number of class
$n_{(c_i)}$ ..... number of observation in class i

Rate of Infestation: $$\frac{\sum_{i=2}^{7}\left(n_{(c_i)}\right)}{\frac{n}{100}}$$

Intensity of Infestation: $$\frac{\sum_{i=2}^{7}\left(n_{(c_i)} * (i-1)\right)}{6 * \sum_{i=1}^{7}\left(n_{(c_i)}\right)}$$

2.7.2 Soil Analysis

Plant-available and amorphous silicon fractions were analyzed in soil samples collected from the top (0-30cm) and subsoil (30-60cm) during the vegetation period at three points of time. The points of time were before the silicon soil amendment, after three silicon applications and after six silicon applications.

The soil amendment treatments were [V1] Soil Amendment, [V3] Soil Amendment + Foliar Spray and [V5] Control – watered. Each treatment is divided into 4 fields with 12 plants. From each field 6 soil samples from the top and subsoil were taken and mixed. Samples were taken three times during the vegetation period. Thus from each treatment 72 (4 fields * 6 samples *3 times) soil samples from the topsoil and 72 samples of the subsoil were taken. Resulting in total of 12 batches of mixed soil samples from the topsoil and 12 batches of mixed soil samples from the subsoil from each treatment.

The level of plant-available silicon in soil was analyzed with a $CaCl_2$-extraction method using a 0.01M solution modified from Haysom and Chapman, 1975 and Liang et al., 2015. 2g of air-dried soil (<2mm) were mixed with 20ml of the 0.01M $CaCl_2$ solution in a tube and were shaken for 16 hours in an overhead shaker and filtrated it with Munktell Ahlstrom paper filters with a grade of 14/N. The amorphous silicon was extracted with a NaOH-extraction method modified from Georgiadis et al. (2015). A 0.2M sodium hydroxide solution was used in a ratio of 1:400 and samples were shaken 120 hours in an overhead shaker. Samples were analyzed in one replicate.

Filtered extracts of both extractions were analyzed colorimetrically with a Varian DMS 200 UV visible spectrophotometer. This analysis is based on the absorptiometric measurement of solutions of reduced β-molybdosilicic acid (modified from Morrison and Wilson, 1963).

Detailed descriptions of the used methods can be found in the Appendix.

2.7.3 Leaf Analysis

To gain knowledge about the amount of silicon allocated to leaves, samples from mature and young leaves were taken at three time points. Mature leaves were taken from the fruit zone and differ in their leaf age from one to another sample time. Young leaves were side shoots of the same developmental stage. The points of time were after 2, 4 and 6 applications of silicon. From each treatment 20 old leaves and 40 young leaves were taken at every sampling time.

Leaves were dried at 65°C for 48 hours in an oven. They were ground with a Retsch ball mill to pass a 20-mesh screen. The amorphous silicon content was extracted by an autoclave-induced extraction method (modified from Elliot and Snyder, 1991). A 50% H_2O_2 -Solution and a 50% NaOH-Solution was added to the plant material and samples were placed in an autoclave at 121°C with a sterilization phase of 20 minutes. Samples were analyzed in one replicate.

Centrifuged (1000 g, 5min, room temperature) extracts were analyzed colorimetrically with a Varian DMS 200 UV visible spectrophotometer (modified from Morrison and Wilson, 1963).

Detailed descriptions of the used methods can be found in the Appendix.

2.7.4 Analysis of Photosynthesis

Hansatech Handy PEA chlorophyll fluorimeter was used for measurement of chlorophyll fluorescence five times during the vegetation period. Any forms of biotic or abiotic stress which have an effect on the photosynthetic performance, will change the intensity of the chlorophyll fluorescence emission. Healthy samples typically achieve a maximum value of Fv/Fm of 0.85. Plants with lower values are exposed to stress, which reduced the capacity for photochemical quenching of energy within photosystem II (Hansatech Handy PEA Manual).

When light energy from the sun is absorbed by a chlorophyll molecule within a sample, the electronic configuration of the molecule is temporarily altered. Photochemical and non-photochemical processes compete to dissipate the absorbed energy. Photochemical processes utilize absorbed energy for the photosynthesis, whereas non-photochemical processes dissipate energy, which is re-emitted in form of infra-red radiation or heat and far-red radiation which is known as chlorophyll fluorescence. A reduction in the rate of one process leads to an increase of the other one e.g. a reduction in the dissipation by photochemistry will be reflected in an increase in energy dissipation by non-photochemical processes such as heat and chlorophyll fluorescence (Emerson et al, 1932).

The parameter Fv/Fm describes the maximum quantum efficiency of photosystem II and the photosynthetic performance. It is presented as the ratio of variable fluorescence (Fv) and the maximum fluorescence value (Fm). It is therefore important that measurements are taken at same environmental conditions (Hansatech Handy PEA Manual)

2.7.5 Fruit Quality Parameters

For the analysis of the quality parameters 30 grapes of each treatment and field were picked at the end of the growing season, crushed and analyzed with a fourier transform infrared spectroscopy (FTIR) OenoFoss™. The must weight, the density, the acidity, the pH-value, the amount of tartaric, malic, acetic and gluconic acid and the amount of alpha amino were gained from this analysis.

The must weight was measured as Klosterneuburger Zuckergrade (°KMW). The must weight is a measure of the amount of sugar in grape juice. Hence indicating the amount of alcohol that could be produced if it is all fermented to alcohol, rather than left as residual sugar. While must weight is a commonly used term among wine makers, the physically correct term would be must density.

There was no analysis of the berry weight because of high damage by Peronospora. This infection led to negative effects on yield formation and therefore it was not possible to compare the impact of silicon onto the size of the clusters.

2.8 **Statistical Analysis**

Statistical analysis of the data was made with the software IBM SPSS Statistics 23. All data were tested on normal distribution and homogeneity of variance. A One-Way ANOVA Post Hoc Multiple Comparison test was used by default to determine differences between the treatments. If assumptions of normal distribution and homogeneity of variance were violated, Man-Whitney U Test, a non-parametric test was used.

3 Results

3.1 Assessment of Fungal Diseases

3.1.1 Powdery Mildew

Powdery mildew was assessed on August 11. Prior to this date only few symptoms were visible. Since the first symptoms appeared, the disease has spread rapidly and intensively. Figure 7 shows that up to 50% of the clusters were infested by the fungi in the control groups [V5] and [V6]. Although it seemed that both the rate and the intensity of the infestation were lower in the silicon treated groups, [V1], [V2] and [V3], statistical analysis could not find significant differences. It can be termed as a trend of reduced infections. Noteworthy to mention is the lower rate of infestation in [V2] silicon foliar spray compared to the [V7] common plant protection control group. Although the intensity of infestation in both treatments [V2] and [V7] is at 10 % and the standard error is similar, statistics could not confirm the findings (α=0.05).

For the analysis in Figure 8 data was grouped to increase the sample size and therefore achieve better statistical results. The first bar “silicon” comprises [V1] Si-soil amendment, [V2] Si-foliar spray and [V3] Si-soil amendment and foliar spray. The control groups [V5] and [V6] were merged in “Control”. The sample size for the common plant protection (CPP) remained the same. The analysis of grouped data shows that the silicon treatments tended to perform better for the rate of infestation than the control group, however, the difference was not statistically significant (α=0.05). The decrease of the intensity of infestation relative to the control group was more pronounced and statistically significant (α=0.05) in the CPP treatment. Relative to the control, the intensity of infestation was significantly reduced both in the CPP and silicon. Therefore, silicon treatments can partly substitute for fungicides while maintaining a similar level of fungal symptoms.

For the assessment of fungal symptoms on the leaves (Figure 9) no differences, nor clear trends can be determined. High infections of downy mildew on the leaves aggravated the optical assessment of powdery mildew. From Figure 9 it can be concluded that no treatment attains better results in the sense of a lower infection of the leaves.

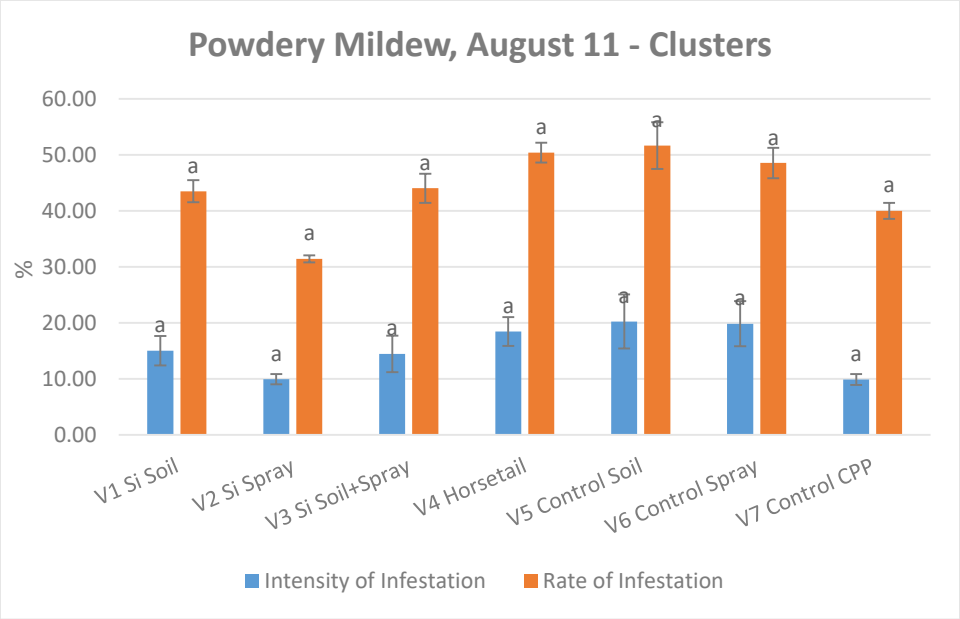

Figure 7: Assessment of powdery mildew of grape clusters on August 11, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean

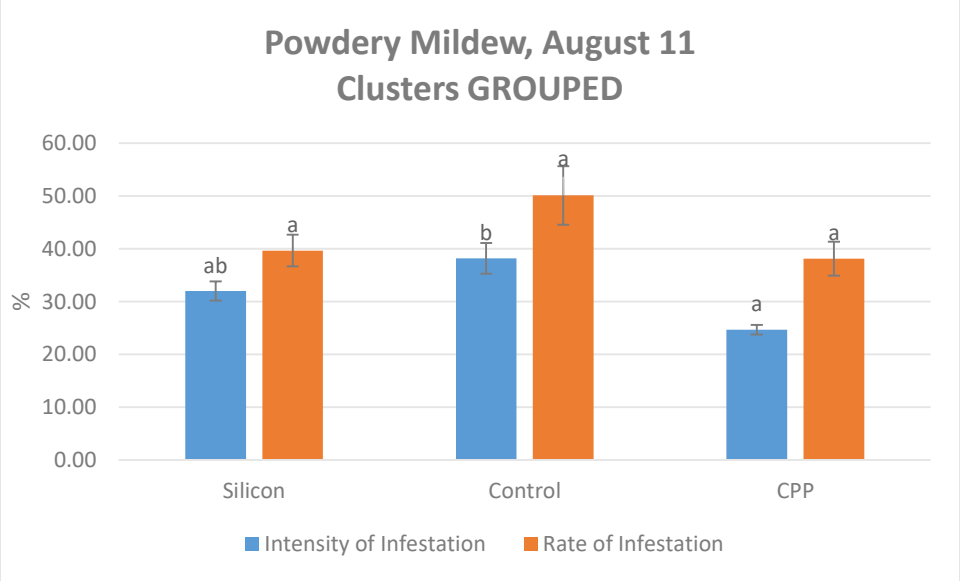

Figure 8: Analysis of grouped data for the assessment of powdery mildew of grape clusters on August 11, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

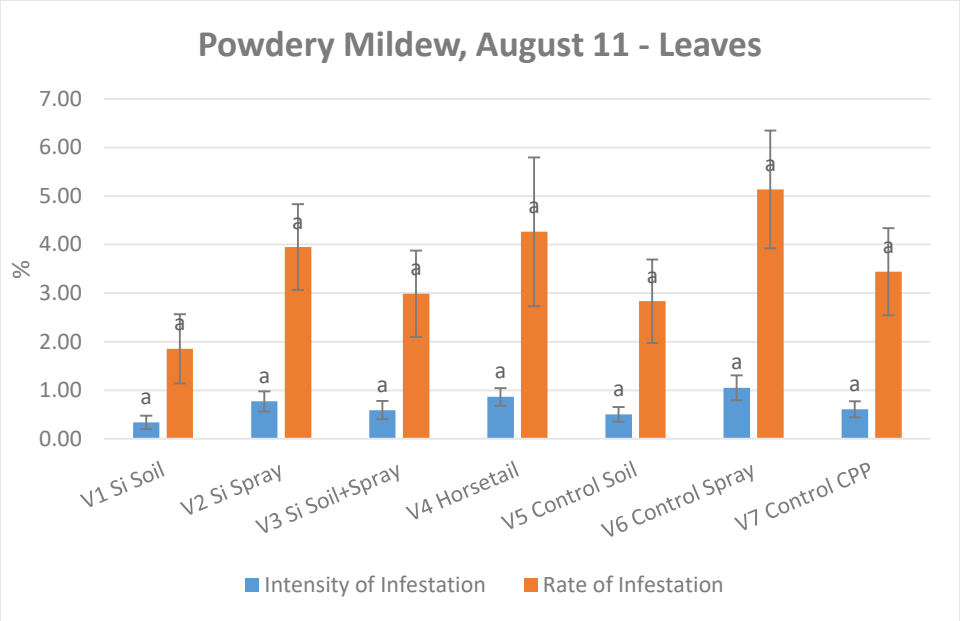

Figure 9: Assessment of powdery mildew of grape leaves on August 11, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

3.1.2 Downy Mildew

Downy mildew was assessed twice on June 24 and August 11. At the first time, the rate of infestation for the clusters was below 15% in all treatments (Figure 10), whereas it increased tremendously up to 90% at the second assessment (Figure 11).

The cluster assessment on June 24 shown in Figure 10 does not give evidence that the silicon treatments are superior compared to the control group. Clearly visible is the higher efficiency of the fungicides in CPP control which is secured statistically for both the intensity and rate of infestation. The assessment of the grape clusters on August 11 (Figure 11) shows a similar pattern. Although the difference between CPP and the other treatments decreased for the intensity and the rate of infestation, it is still significant that fungicide application provided better protection for downy mildew regarding the rate of instestaton.

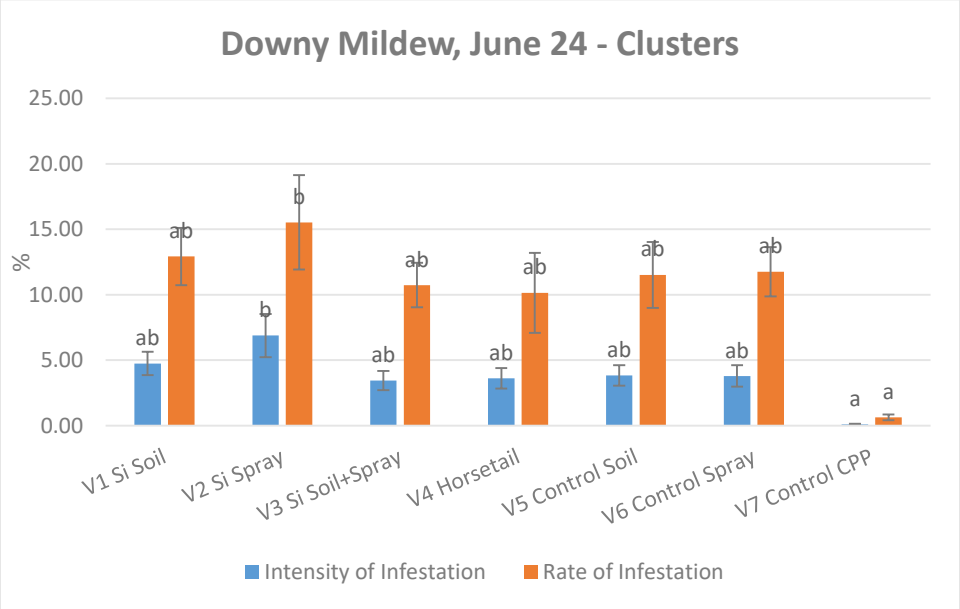

Figure 10: Assessment of downy mildew of grape clusters on June 24, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

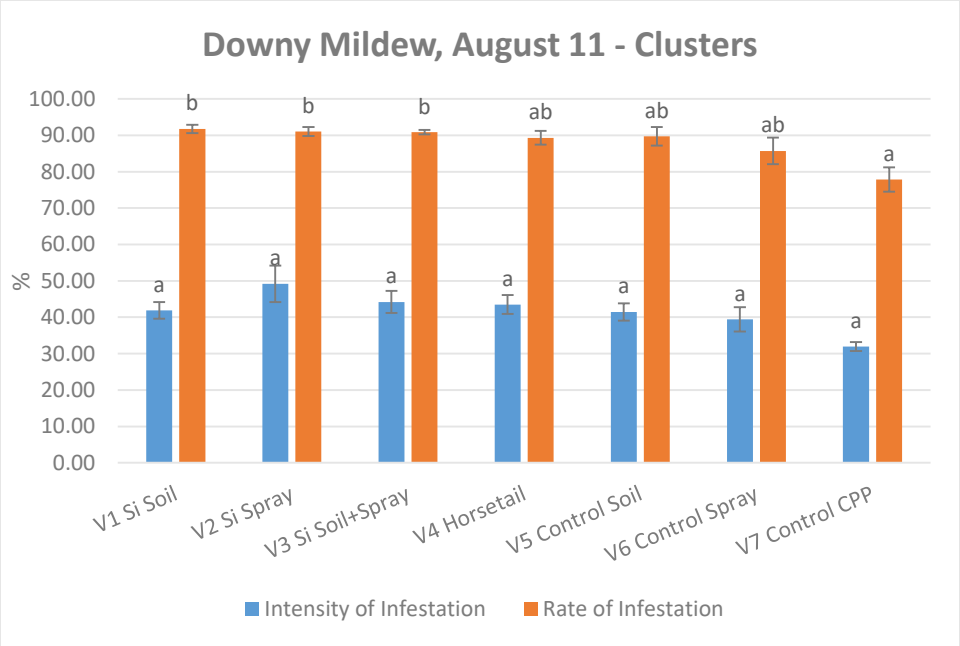

Figure 11: Assessment of downy mildew of grape clusters on August 11, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

One may conclude from the analysis of the symptoms on the leaves from downy mildew (Figures 12 and 13) that silicon treatments cannot better fight off the fungal pathogen than in the control group. The systemic fungicides in the CPP group show significantly better results on June 24 for the rate of infestation. On August 11, both the intensity of infestations and the rate of infestation, were distinguishable from the other treatments and showed lower infections.

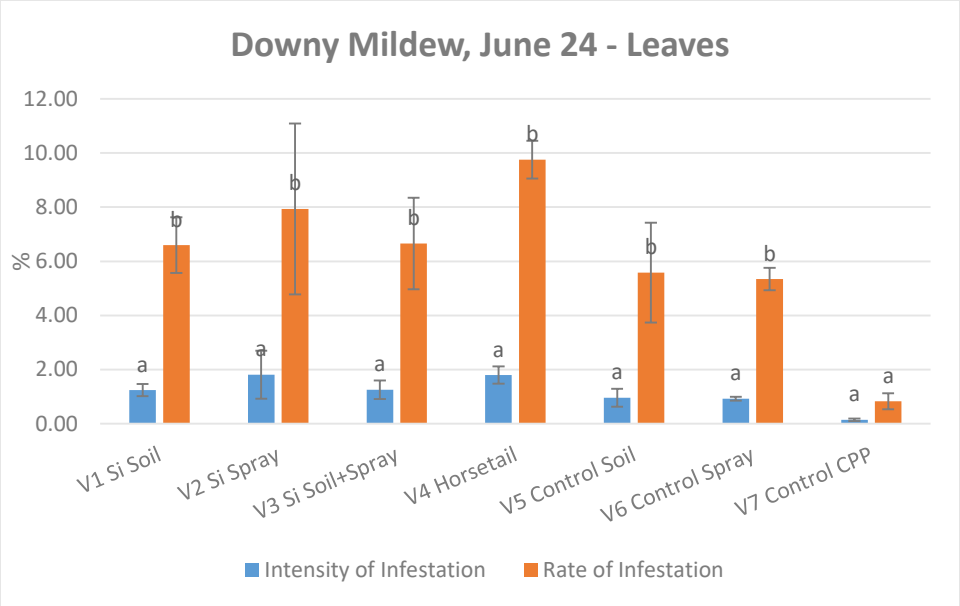

Figure 12: Assessment of downy mildew of grape leaves on June 24, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

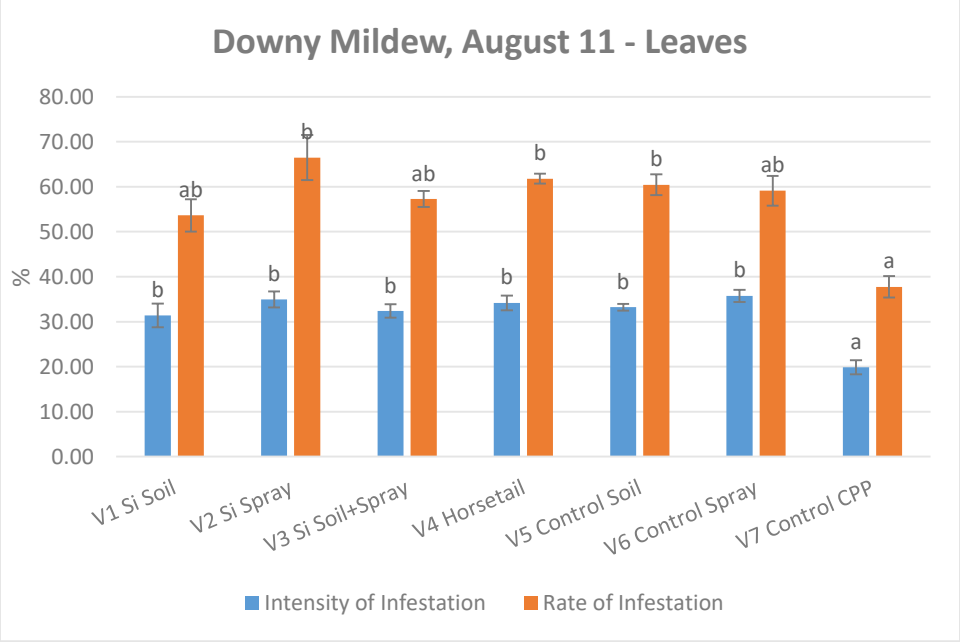

Figure 13: Assessment of downy mildew of grape leaves on August 11, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

3.2 **Silicon Status in Soil**

3.2.1 Plant-Available Silicon

The efficiency of the silicon soil amendment can be clearly seen in Figure 16, where the level of plant-available silicon in the topsoil (0-30 cm) is shown. All results fall within the typical range of 0.029 – 0.175 mM plant-available silicon reported in the literature (Epstein, 1994).

The first bar (T1) indicates the soil analysis before the Si applications. At this time no differences in the level of plant-available silicon could be detected for the treatments. After three Si-applications (T2) the level of plant-available silicon increased in the Si-soil amendment [V1] and the Si-soil amendment + foliar spray [V3] significantly relative to the control group [V6], which remained unchanged. After six Si applications (T3) the level of silicic acid still increased to a higher level and was significantly different to the [V6] control group. Probably due to higher temperatures and thus higher microbial activity and dissolution rates the level of silicic acid also increased in the [V6] control group.

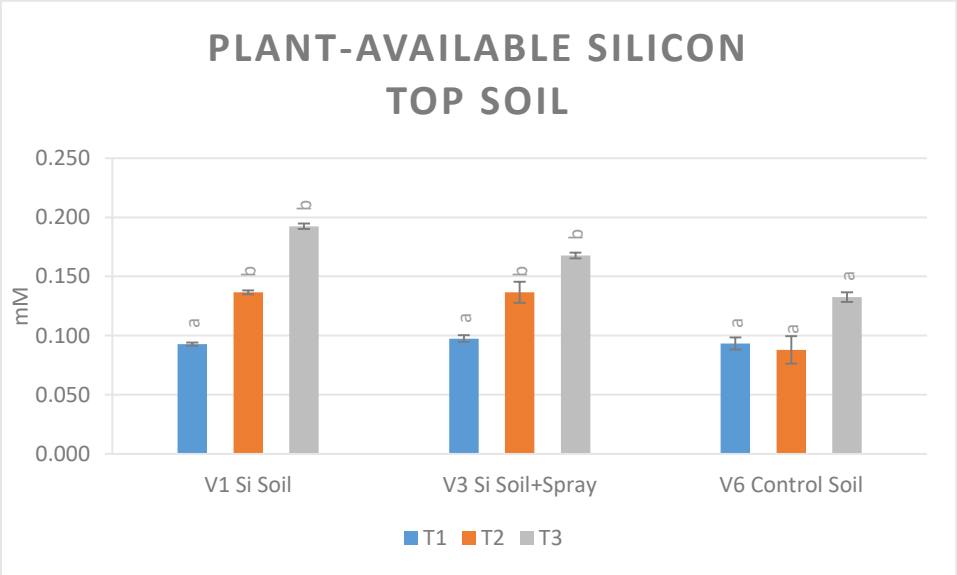

Figure 14: Plant-available silicon in the topsoil, T1: date of sample one on May 17, 2016, T2: date of sample two on July 5, 2016, T3: date of sample three on August 25, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

The plant-available Si fraction in the subsoil (30-60 cm) shows similar trends (Figure 17), whereas no statistical significance could be detected. In both Si treatments, [V1] and [V3], the level of plant-available silicon shows an accumulative trend. From the analysis of the topsoil (Figure 16) and the subsoil (Figure 17) it can be expected that the differences between soil amendment and control group diminish with increasing depth of the soil.

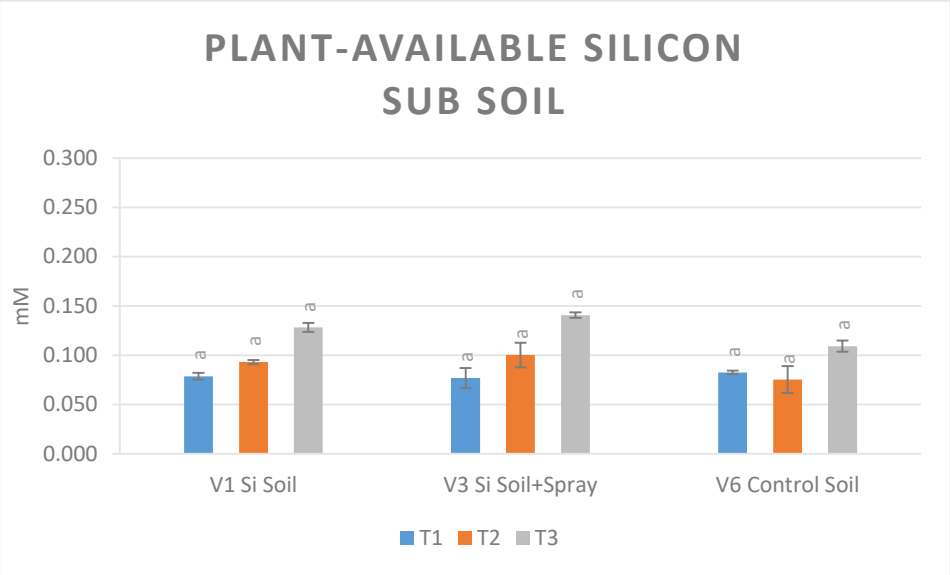

Figure 15: Plant-available silicon in the subsoil, T1: date of sample one on May 17, 2016, T2: date of sample two on July 5, 2016, T3: date of sample three on August 25, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

3.2.2 Amorphous Silicon

The enrichment of the amorphous Si fraction worked well in the topsoil as can be seen in Figure 16. Amorphous Silicon ranges from 1000 to 30000 mg/kg in soil (Epstein, 1994). In the Si-amended soil treatment [V1], the level of amorphous silicon doubled from 1500 mg/kg (T1) to 3000 mg/kg (T3). For the treatment Si-soil + foliar spray treatment [V3] a similar but less pronounced trend was observed. The amount in the control group [V6] remained stable over time.

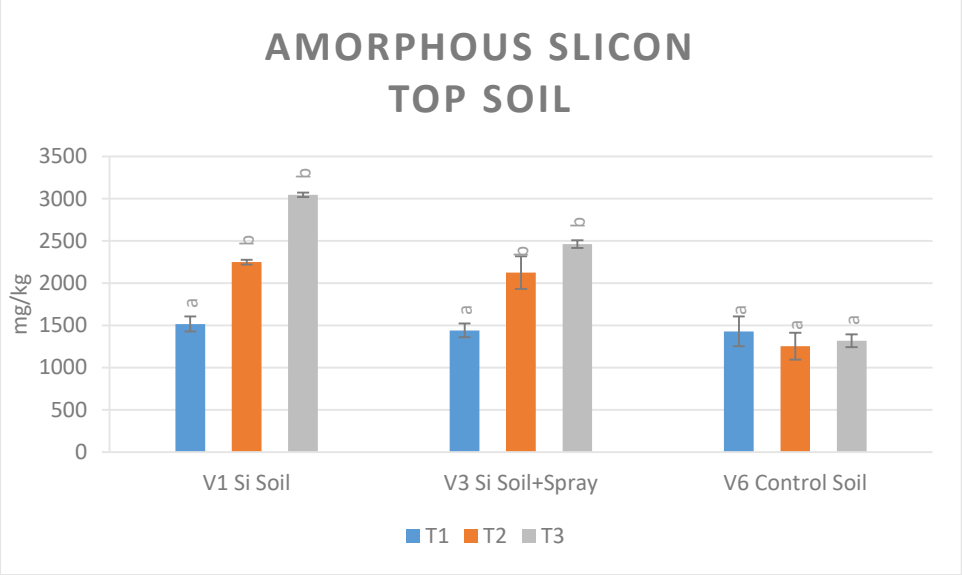

Figure 16: Amorphous silicon in the topsoil, T1: date of sample one on May 17, 2016, T2: date of sample two on July 5, 2016, T3: date of sample three on August 25, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

Significant differences can be found for the subsoil as well (Figure 17). Soil with Si-soil amendments show increased levels of amorphous silicon compared to the control group. Compared to the topsoil the amplitude of the rise is not that high in the subsoil, but clearly visible and statistically significant.

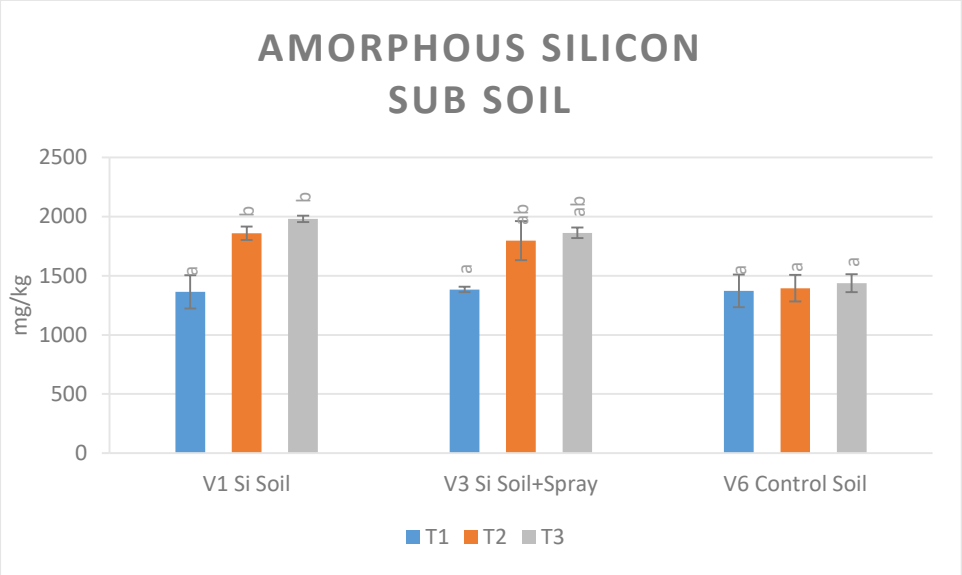

Figure 17: Amorphous silicon in the subsoil, T1: date of sample one on May 17, 2016, T2: date of sample two on July 5, 2016, T3: date of sample three on August 25, 2016One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

3.3 Leaf Analysis

The Si concentration of mature leaves (Figure 18) increases with leave age. Clearly visible is the boost of Si concentrations in the treatments with foliar spray [V2] and the combined soil amendment + foliar spray [V3]. Since the treatment Si soil amendment [V1] does not show an increased level of Si compared to the control groups, one can conclude that only the foliar spray increased the level of Si in the leaves.

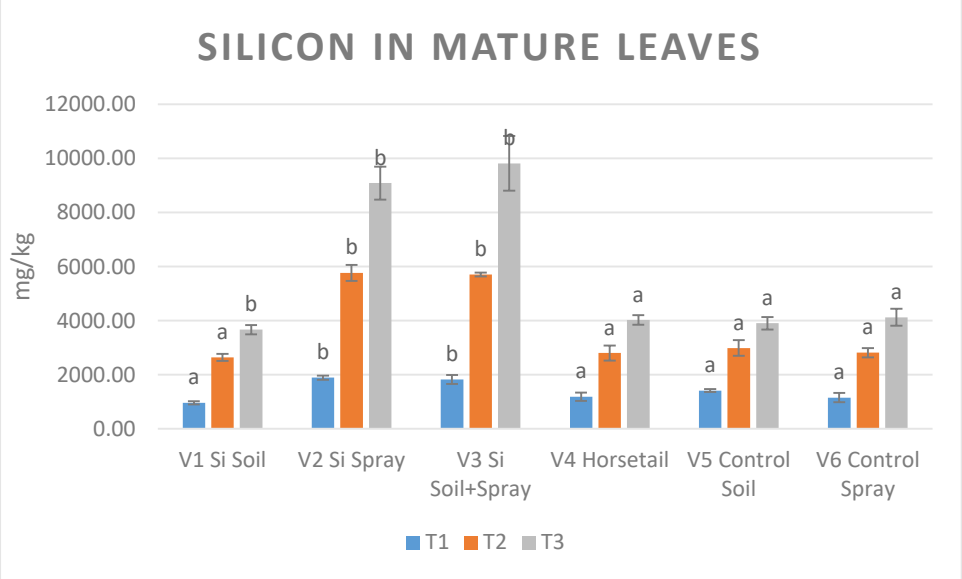

Figure 18: Silicon concentrations of mature grapevine leaves. T1: date of sample one on June 21, 2016, T2: date of sample two on July 20, 2016, T3: date of sample three on August 25, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

The Si level in young leaves was initially much lower at around 200 mg/kg (Figure 19) than for mature leaves which were general > 1000 mg/kg. At time T2, the treatments [V2] and [V3] exceeded 1000 mg/kg also in younger leaved and were statistically distinguishable from the control groups [V5] and [V6]. Surprising is the last sample at T3 where all treatments show highly elevated amounts of Si and the treatments [V2] and [V3] even surpass the Si levels of the mature leaves.

Noteworthy is the significant difference between Si-foliar spray [V2] and the soil amendment + foliar spray [V3] at time T3. Although the soil amendment in [V1] does not show elevated levels of foliar Si, the combination of soil amendment and foliar spray in treatment [V3] seems to further increase the silicon deposits in the leaves.

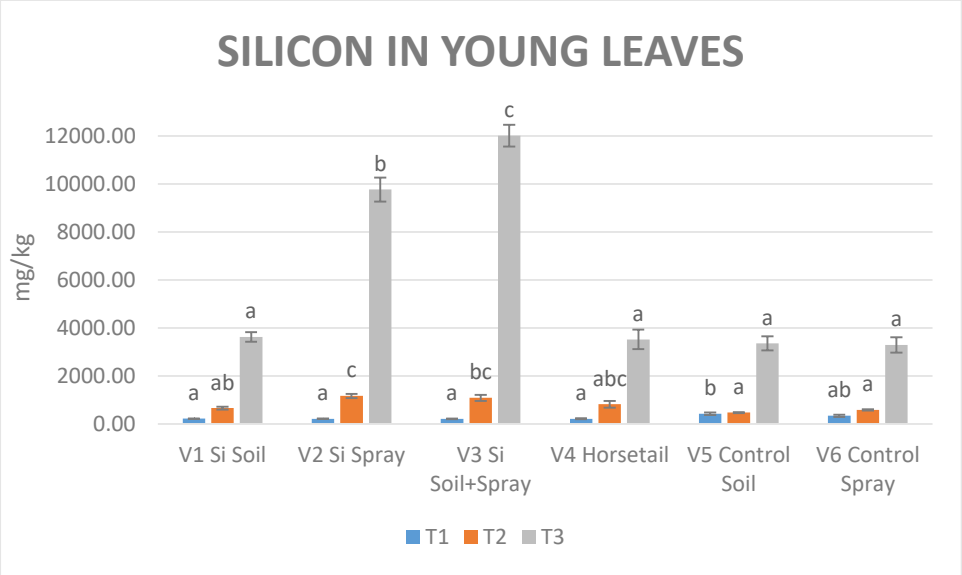

Figure 19: Silicon concentrations of young grapevine leaves, T1: date of sample one on June 21, 2016, T2: date of sample two on July 20, 2016, T3: date of sample three on August 25, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

3.4 **Photosynthesis**

The results of the chlorophyll fluorescence for mature leaves (Figure 20) showed at times T3 and T4 significant reductions in the CPP control group [V7]. The analysis of the chlorophyll fluorescence of young leaves (Figure 21) shows similar results. There is no data in T1 because the first appearing grapevine leaves are included in the mature leaves.

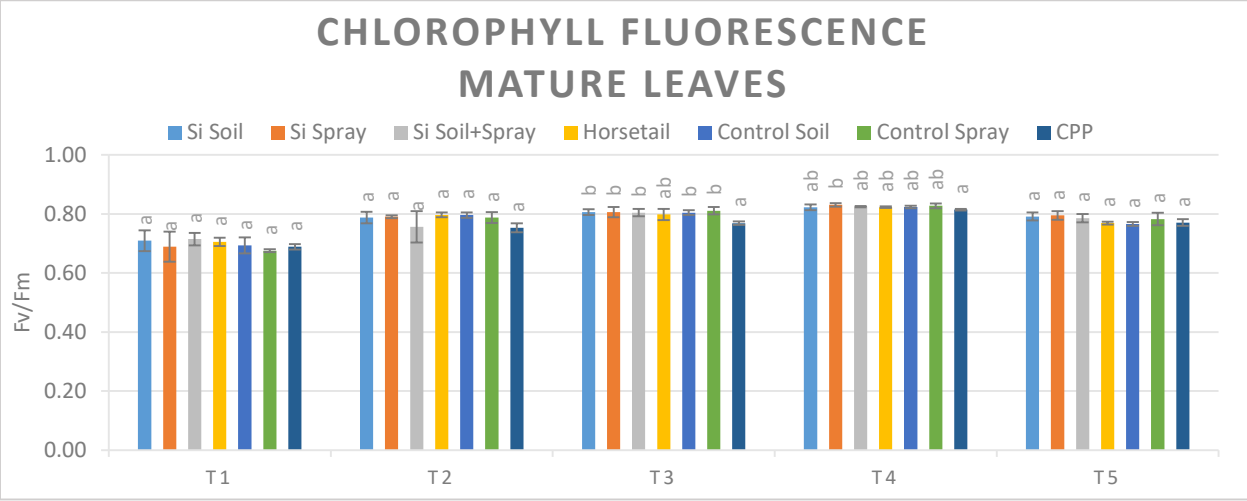

Figure 20: Chlorophyll florescence of mature grapevine leaves, T1: date of sample one on May 30, 2016, T2: date of sample two on June 16, 2016, T3: date of sample three on July 5, 2016, T4: date of sample four July 28, 2016, T5: date of sample five on August 16, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

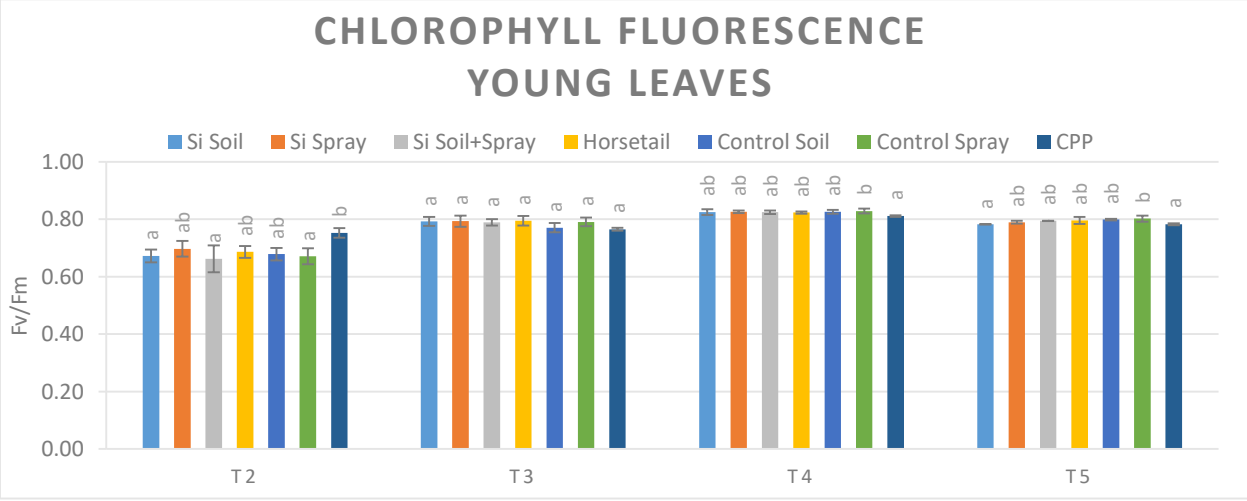

Figure 21: Chlorophyll florescence of young grapevine leaves, T1: date of sample one on May 30, 2016, T2: date of sample two on June 16, 2016, T3: date of sample three on July 5, 2016, T4: date of sample four July 28, 2016, T5: date of sample five on August 16, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

3.5 Fruit Quality Parameters

The analysis of the fruit quality parameters gives a consistent picture. There is no treatment which enhances the quality of one or more parameters of the fruit juice (Table 7). The only exception is the amount of alpha amino acids (Figure 22) when grouped into categories “Silicon”, “Control” and “CPP”. Silicon treated vines show elevated values of amino acids compared to the control group and CPP.

Treatment	°KMW	Density	pH	Acidity (g/l)	Tartaric Acid (g/l)	Malic Acid (g/l)	Acetic Acid (g/l)	Gluconic Acid (g/l)	Alpha Amino (mg/l)
V1	15.73	1.08	3.10	8.73	7.74	3.34	0.01	0.56	193.60
V2	15.98	1.08	3.11	9.05	7.81	3.79	0.04	0.56	192.90
V3	15.78	1.17	3.12	8.83	7.73	3.66	0.03	0.65	186.18
V4	15.93	1.08	3.12	8.93	7.80	3.74	0.04	0.60	188.65
V5	15.83	1.08	3.09	9.14	7.96	3.80	0.03	0.53	175.74
V6	15.33	1.08	3.11	8.96	7.65	3.61	0.02	0.49	180.61
V7	15.35	1.16	3.12	8.65	7.59	3.34	0.03	0.44	157.39

Table 10: Means of fruit quality parameters

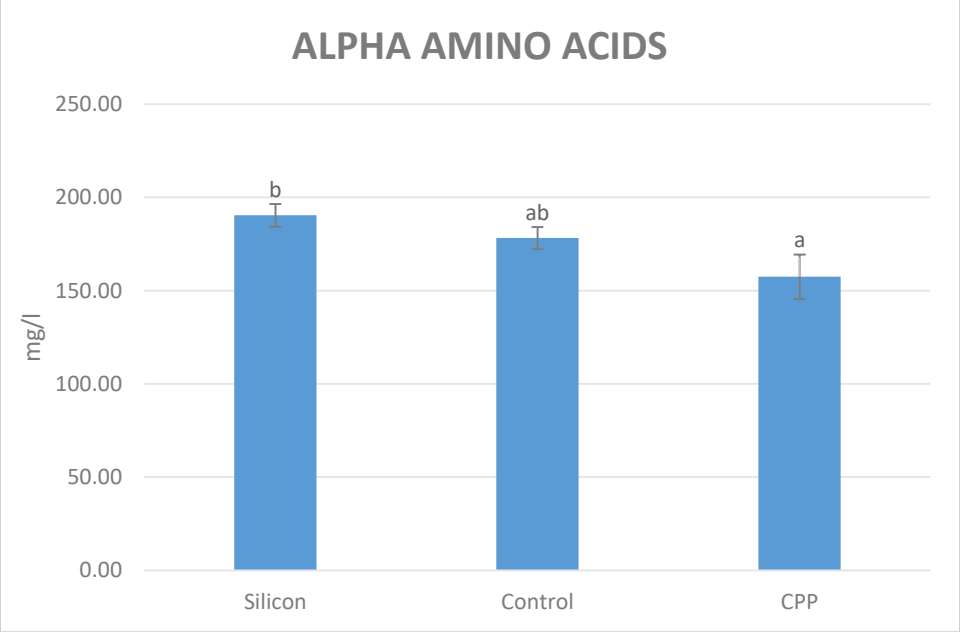

Figure 22: Analysis of alpha amino acids in the fruit juice, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

4 Discussion

Silicon application could be a promising approach for sustainable, environmentally sound and broad-spectrum control of fungal diseases in viticulture like it already is in other agricultural contexts. Applications of silicon can enhance the resistance of certain susceptible cultivars to the same level as those that have complete genetic resistance (Sakr, 2016). Since the effect on enhancing plant resistance against fungal pathogens is not limited to high Si accumulators, this thesis has been carried out to investigate the protective role of Si for grapevine, a low Si-accumuator. We tested one of the two mechanisms of silicon-enhanced fungal resistance based on higher silicon deposits in the plant.

Colloidal Silica as a 50% wt. suspension in water was used for the soil amendment and the foliar spray. The advantage of this product is that no influence of other nutrients is given like in other Si-fertilizers, which can contain potassium or calcium for example. However, slag-based silicate fertilizers are more cost-effective. In the field more attention should be paid for slag-based silicates due to their potential environmental risks which may arise from the heavy metals contained in the fertilizers. Soluble potassium or sodium silicates are completely water soluble and can be used as foliar fertilizers, but are usually too expensive for soil application. Slow-releasing potassium-containing or potassium-rich silicates that are manufactured using feldspar as raw materials are not only cost-effective and agriculturally effective but also environmentally friendly.

During the vegetation period 2016 a high risk of fungal infections was given. This led to an extreme spread of downy and powdery mildew for grapevine and brought all plant protection products to their limits. The optical assessment of one disease was aggravated by the symptoms of the other and made it difficult for the assessing persons to identify coinfections. Nonetheless there is evidence that Si-treated grapes showed a trend towards less infection for powdery mildew. Silicon treatments can partly substitute for fungicides while maintaining a similar level of fungal symptoms. For downy mildew, no differences in the extent of symptoms could be determined. The findings conform to Reynolds et al. (1995) and Bowen et al. (1992) who also detected reduced powdery mildew infections for Si-sprayed vines compared to a non-treated control.

The content concentration of leaves only increased with the silica foliar spray. The obtained results from the analysis of the Si deposits in the leaves are in the range of the findings of Lafos (1995), who studied the uptake of silicon for grapevine. The silicon concentrations of foliar treatments fluctuated between 170 – 15,800 mg/kg and average at 2,150 mg/kg dry mass. Comparing this with the maximum values of 10,000 mg/kg for mature leaves, leads to the conclusion that the amount of the foliar applied silicon could have been higher concentrated. It can also be possible that the uptake of the leaf was too slow for gaining even higher levels and applied silicon got washed up by precipitation. Mature leaves correlate in both studies with leaf

age and the number of Si applications, thus confirming that silicon is transported in the xylem and is accumulated in the leaves. The Si concentration in young leaves at the same developmental stage increased with the number of foliar Si applications. Blaich and Grundhöfer, (1998) found substantially more Si deposits in infected compared to uninfected leaves. They suggested that this might be a mechanism to fight off penetrating mycelium by the localized accumulation of silicates in the cell wall (Blaich and Wind, 1989). The enormous increase in Si deposits at the last sample date of the young leaves can be associated with the defense mechanism due to a prior period of high infections.

Lafos (1995) stated also a 10% reduction of powdery mildew upon Si fertilization compared to a non-treated control group in the greenhouse, which could not be confirmed in our field experiment. Comparing the content of silicon in the soil with the amount of silicon soil amendment of 2.5t silica per hectare shows that it was sufficient. The plant-available silicon was raised significantly to a high level. Unfertilized soils range from 0.029 to 0.175 mM plant-available silicon (Epstein, 1994), whereas the soil in the Si-fertilized treatments showed levels of up to 0.190 mM in the topsoil. In the subsoil a minor increase could be detected. Referring to the amorphous silicon fraction, the amount of 2.5t silica per hectare increased the level of 1,500 up to 3,000 mg/kg. Compared to the range of 1,000 to 30,000 mg/kg amorphous silicon in soils (Epstein, 1994) this amount is low. An increase in plant-available silicon due to hydration of amorphous silicon can be expected in the next years. Although the amendment of the soil worked well for both Si fractions in the topsoil, the effect was always less pronounced in the subsoil. Accordingly, it can be expected that parts of the roots in the deeply rooted loess soil did not benefit from the silicon applied to the soil during the vegetation period.

The horsetail extraction treatment showed neither increased levels of Si in the leaves nor reduced mildew symptoms. Since no detailed analysis of the specific compounds of the horsetail extraction product is available one can only speculate why an increased silicon concentration could not be detected. The silicon availability could be lower than for the LUDOX colloidal silica suspension. Furthermore, the horsetail extract could contain amorphous phytoliths, which show lower plant-availability. The application was conducted according to the guideline for the product for viticulture. In addition, no increased photosynthetic activity was observed for this treatment.

Overall no enhanced photosynthetic activity could be determined for any treatment. However, the common plant protection treatment showed reduced photosynthetic activity at two out of five dates. These dates correspond to a time of high systemic fungicide applications for this treatment and make it evident that intense spraying of systemic fungicides disturbs the plants physiology.

Silicon applications did not increase sugar content or acidity levels of the berries. Due to generally high damage caused by downy mildew, the weight of the clusters could not be determined and compared between the treatments. Differences in the level of amino acids were found and were higher for the Si-treated grapes. Low values of amino acids, also termed yeast-assimilable nitrogen (YAN), are the cause of sluggish fermentations often leading to off-flavors in the wine

(Ribéreau-Gayon et al., 2006). Reduced levels of YAN are associated with bunch rot on the grapes or with vines suffering from drought conditions (Ribéreau-Gayon et al., 2006). Applying silica to gain higher levels of YAN could provide a welcomed tool especially in view of expected temperature rise caused by global warming. Additionally, referring to bunch rot, another fungal pathogen for grapevine which consumes amino acids, increased levels of YAN could be a hint for another potential fungal pathogen, which could be alleviated by silica applications.

Although foliar Si application may be effective in reducing many foliar diseases, applying silicon to the roots through the soil pathway may be even more effective because it mediates the plant's defense responses to both foliar and root infections (Datnoff et al., 2015). Only when applied to the roots, Si will change plant responses to pathogen infections at both the physiological and molecular level. This implies an active role for Si in one or more plant defense signaling pathways. Therefore, it is necessary to find a better way to fertilize vines in the field with Si. A plain alternative is to run the experiment on a site with low soil depth, where root growth is constricted by underlying rocks and are forced to develop near the surface of the soil. Fertilizing silica will then lead to an increased concentration of silicic acid in the main root zone. Another approach is to get the silica into deeper soil layers by letting it flow through a dug pipe to the right spot. A third idea is letting the silicic acid get transported into deeper layers by precipitation over time. However, this method is time consuming and could take years to reach a favored concentration of silicic acid also in the deeper root zone.

The uptake by the roots would support a continuous enrichment, which is important for the disease-suppressing effects. These will be reduced or non-existent if the continuity is disturbed. For any plant disease, a minimum silicon concentration is needed to suppress a disease. Once that level has been obtained, plant disease suppression increases proportionally as the silicon concentration increases in plant tissues (Datnoff et al., 2015). Therefore, it is substantial that this level of minimum silicon concentration is met early in the vegetation period to fully protect the vines from mildew infections. The time for the highest infection risk for grapevine is from pre-flowering (BBCH 60) to pea-sized berries (BBCH 75). Intensive silica foliar applications early in the season combined with a sap flow enriched with silicic acid taken up from the root zone are probably crucial for sufficient protection.

An analysis of biochemical defense mechanisms of the vines would have exceeded the workload of this thesis. Nevertheless, some thoughts can be given to it. Plants supplied with Si exhibit potentiated activation of the phenylpropanoid pathway resulting in increases in total soluble phenolics and lignin (Datnoff et al., 2015). Although playing an important role for defense, increased levels of phenolics in grape berries could have a negative impact on the wine due to bitter compounds (Ribéreau-Gayon et al., 2006). The activities of defense enzymes in Si-treated plants, such as chitinases and β-1,3-glucanases, are maintained at higher levels during infection and the transcription of defense-related genes occurs faster and with greater output (Datnoff et al., 2015). These PR proteins are significantly increased in powdery mildew infected grape leaves

and pre-veraison berries and it was shown that they can cause lysis of E*. necator* germ tubes in vitro (Gadoury et al., 2012).

Further research in this field should focus on the biochemical defense mechanisms of grapevine like PR-proteins and phytoalexins and the expression of genes associated with these defense mechanisms. Systemically acquired resistance (SAR) or induced systemic resistance (ISR) pathways are associated with higher levels of salicylic acid, jasmonic acid and ethylene, which have been reported to be induced by Si supplements in a number of host-pathogen interactions (Tubana et al., 2015) and could also be of major interest in viticulture. Moreover, an overview of different vineyard soils focusing on the levels of silicon fractions would give new inputs for soil-plant-interactions and will bring light into possible Si deficiencies.

Since the introduction of pests for grapevine *Vitis vinifera* in the middle of the 19th century in Europe, much effort has been put into plant protection strategies. Nowadays intensive use of chemical protection, with all its negative side effects, is still the most widespread approach to control fungal pathogens in viticulture. This study tried to find an alternative approach using silica as controlling agent for powdery and downy mildew. Photosynthetic measurements confirm that systemic fungicides do not only harm the environment, but also hinder the vine's physiology by inducing abiotic stress. However, fungal assessments in our study determined a trend of reduced infections of powdery mildew in silica treatments. Closer intervals and better timed applications will potentially foster the effectiveness of silica foliar sprays.

5 Literature

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6 Appendix

6.1 EPPO Standard Uncinula necator PP 1/4(4)

European and Mediterranean Plant Protection Organization
Organisation Européenne et Méditerranéenne pour la Protection des Plantes

PP 1/4(4)

Efficacy evaluation of fungicides
Uncinula necator

Specific scope
This standard describes the conduct of trials for the efficacy evaluation of fungicides against *Uncinula necator*, causing powdery mildew of grapevine.

Specific approval and amendment
First approved in 1977-09.
Revision approved in 1987-09.
Aligned with revised standard text in 1996.
Revision approved in 2001-09.

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1. Experimental conditions

1.1 Test organisms, selection of crop and cultivar

Test organism: *Uncinula necator* (UNCINE).
Only productive grapevine *Vitis vinifera* (VITVI) of the same susceptible cultivar, rootstock habit and age, should be used.

1.2 Trial conditions

The trial should be set up in the field. The vineyard should be homogeneous in cultivar, age, plant width, training system, rootstock and general cultivation and health status. Cultural conditions (e.g. soil type, fertilization) should be uniform for all plots of the trial and should conform with local agricultural practice. Microclimate conditions should as far as possible be homogeneous, particularly with respect to altitude, slope and wind exposure. The trial should form part of a trial series carried out in different regions with distinct environmental conditions
and preferably in different years or growing seasons (see EPPO Standard PP 1/181 Conduct and reporting of efficacy evaluation trials).

1.3 Design and lay-out of the trial

Treatments: test product(s), reference product and untreated control, arranged in a suitable statistical design. Plot size (net): at least 10 vines (or sufficient to provide at least 100 leaves and at least 50 bunches for assessment, as in 3.2) on 3 rows. Sample size may be increased (e.g. 150 leaves and 100 bunches) if the intensity of the disease is not expected to be high. Replicates: at least 4. For further information on trial

2. Application of treatments

2.1 Test product(s)

The product(s) under investigation should be the named formulated product(s) (see EPPO Standard PP 1/181 Conduct and reporting of efficacy evaluation trials).

2.2 Reference product

The reference product should be a product known to be satisfactory in practice under the agricultural, plant health and environmental (including climatic) conditions in the area of intended use. In general, type of action, time of application and method of application should be as close as possible to those of the test product.

2.3 Mode of application

Applications should comply with good standard practice.

2.3.1 Type of application
The type of application (e.g. a spray or a dust) should be as specified for the intended use.

2.3.2 Type of equipment
Application(s) should be made with equipment which provides an even distribution of product on the whole plot or accurate directional application where appropriate, equivalent to good commercial practice. Factors which may affect efficacy (such as operating pressure, nozzle type) should be chosen in relation to the intended use.

2.3.3 Time and frequency of application
The number of applications and the date of each application should be as specified for the intended use. The 1st application is normally made at BBCH growth stage 13-14 (3-4 leaves unfolded).

2.3.4 Doses and volumes
The product should normally be applied at the dosage specified for the intended use. Doses higher or lower than the intended dose may be tested to determine the margin of effectiveness and crop safety. The dosage applied should normally be expressed in kg (or L) of formulated product per ha. It may also be useful to record the dose in g of active substance per ha. For sprays, data on concentration (%) and volume (L ha^{-1}) should also be given. Deviations from the intended dosage should be noted.

2.3.5 Data on other plant protection products
If other plant protection products (or any biocontrol agents) have to be used, they should be applied uniformly to all plots, separately from the test product and reference product. Possible interference with these should be kept to a minimum.

3. Mode of assessment, recording and Measurements

3.1 Meteorological and edaphic data

3.1.1 Meteorological data
On the days before and after application, meteorological data should be recorded which is likely to affect the development of the crop and/or pest and the action of the plant protection product. This normally includes data on precipitation and temperature. All data should preferably be recorded on the trial site, but may be obtained from a nearby meteorological station. On the date of application, meteorological data should be recorded which is likely to affect the quality and persistence of the treatment. This normally includes at least precipitation (type and amount in mm) and temperature (average, maximum, minimum in °C). Any significant change in weather should be noted, and in particular its time relative to the time of application. Throughout the trial period, extreme weather conditions, such as severe or prolonged drought, heavy rain, late frosts, hail, etc., which are likely to influence the results, should also be reported. All data concerning irrigation should be recorded as appropriate.

3.1.2 Edaphic data
Not required.

3.2 Type, time and frequency of assessment

The BBCH growth stage of the crop at each date of application and assessment should be recorded.

3.2.1 Type
Assessment on leaves
For each plot, the percentage of leaf area affected should be assessed on at least 100 leaves randomly selected, from the same position on the shoot.

Assessment on fruits
For each plot, the percentage infected area of at least 50 randomly selected bunches should be assessed.
See Appendix I for scales that may be used.

3.2.2 Time and frequency
Assessment on leaves A preliminary assessment is made immediately before application, and a final assessment is made at berry ripening (BBCH 81-89). Intermediate assessments may be made.

Assessment on fruits
Assessments are made at the fruitsetting stage (BBCH 71) and at the beginning of ripening (BBCH 81). An additional assessment may be useful at the end of ripening (BBCH 89).

3.3 Direct effects on the crop
The crop should be examined for the presence of phytotoxic effects (or visible remains of the product). In addition, any positive effects should be noted. The type and extent of such effects on the crop should be recorded and, if there are no effects, this fact should also be recorded. Phytotoxicity should be scored as follows:

(1) if the effect can be counted or measured, it should be expressed in absolute figures;
(2) in other cases, the frequency and intensity of damage should be estimated. This may be done in either of two ways: each plot is scored for phytotoxicity by reference to a scale, or each treated plot is compared with an untreated plot and percentage phytotoxicity estimated.

In all cases, symptoms of damage to the crop should be accurately described (stunting, chlorosis, deformation, etc.). For further details, see EPPO Standard PP 1/135 Phytotoxicity assessment which contains sections on individual crops.

It may be useful to assess effects on oenological and organoleptic quality using appropriate methodology (see EPPO Standard on oenological testing, in preparation); such information may come from an additional trial. In particular, attention should be paid

to palatability and flavour of table grapes.

3.4 Effects on non-target organisms

3.4.1 Effects on other pests
Any observed effects, positive or negative, on the incidence of other pests should be recorded.

3.4.2 Effects on other non-target organisms
Any observed effects, positive or negative, on naturally occurring or introduced pollinators or natural enemies should be recorded. Any observed effect, positive or negative, on adjacent or succeeding crops should be recorded. Any environmental effects should also be recorded, especially effects on wildlife.

3.5 Quantitative and qualitative recording of yield

Not required. The grapes harvested in the various plots may be weighed but extrapolation of the data is only valid if the vineyard is homogeneous.

4. Results

The results should be reported in a systematic form and the report should include an analysis and evaluation. Original (raw) data should be available. Statistical analysis should normally be used, by appropriate methods which should be indicated. If statistical analysis is not used, this should be justified. See EPPO Standard PP 1/152 Design and analysis of efficacy evaluation trials

Appendix I

To assess percentage of leaf surface and bunch area affected, a scale such as the following may be used and should be described:

1 = no disease;
2 = <5%;
3 = 5-10%;
4 = 10-25%;
5 = 25-50%;
6 = 50-75%;
7 = >75%.
(from EPPO Standard PP 1/31 *Plasmopara viticola*)

1 = no disease;
2 = 1-5 %;
3 = 5-25 %;
4 = 25-50%;
5 = >50%.
(from EPPO Standard PP 1/17 *Botryotinia fuckeliana* on grapevine, bunch area affected)

6.2 EPPO Standard Plasmopara viticola PP 1/4(4)

European and Mediterranean Plant Protection Organization
Organisation Européenne et méditerranéenne pour la Protection des Plantes

PP 1/31(3)

Efficacy evaluation of fungicides
Plasmopara viticola

Specific scope
This standard describes the conduct of trials for the efficacy evaluation of fungicides against *Plasmopara viticola*, causing downy mildew of grapevine.

Specific approval and amendment
First approved in 1980-09.
Aligned with revised standard text in 1996.
Revision approved in 2000-09.

1. Experimental conditions

1.1 *Test organisms, selection of crop and cultivar*

Test organism: *Plasmopara viticola* (PLASVI).
Crop: grapevine *Vitis vinifera* (VITVI).

1.2 *Trial conditions*

The trial should be set up in the field in productive vineyards with natural infection but, in certain circumstances, it may be necessary to carry out the trial on special small plots, with artificial inoculation and misting in order to enhance infection. Cultural conditions (e.g. soil type, fertilization) should be uniform for all plots of the trial and should conform with local viticultural practice. The trial should preferably be set up in a topographically and climatically homogeneous environment favorable to the pathogen. The trial should form part of a trial series carried out in different regions with distinct environmental conditions and preferably in different years or growing seasons (see EPPO Standard PP 1/181 Conduct and reporting of efficacy evaluation trials).

1.3 *Design and lay-out of the trial*

Treatments: test product(s), reference product and untreated control, arranged in a suitable statistical design. Plot size (net): sufficient to provide at least 100 bunches per plot for natural infection or 50 bunches per plot when artificial inoculation is used.
Replicates: at least 4. For further information on trial design, see EPPO Standard PP 1/152 Design and analysis of efficacy evaluation trials.

2. Application of treatments

2.1 *Test product(s)*

The product(s) under investigation should be the named formulated product(s) (see EPPO Standard PP 1/181 Conduct and reporting of efficacy evaluation trials).

2.2 *Reference product*

The reference product should be a product known to be satisfactory in practice under the agricultural, plant health and environmental (including climatic) conditions in the area of intended use. In general, type of action, time of application and method of application should be as close as possible to those of the test product.

2.3 *Mode of application*

Applications should comply with good standard practice.

2.3.1 *Type of application*

The type of application (e.g. a spray) should be as specified for the intended use.

2.3.2 *Type of equipment*

Application(s) should be made with equipment which provides an even distribution of product on the whole plot or accurate directional application where appropriate, equivalent to a good commercial practice. Factors which may affect efficacy (such as operating pressure, nozzle type) should be chosen in relation to the intended use.

2.3.3 *Time and frequency of application*

The number of applications and the date of each application should be as specified for the intended use.

2.3.4 *Doses and volumes*
The product should normally be applied at the dosage specified for the intended use. Doses higher or lower than the intended dose may be tested to determine the margin of effectiveness and crop safety. The dosage applied should normally be expressed as a concentration (%) combined with a volume (L ha^{-1}) appropriate to the state of the crop. These should be recorded together with the dosage in kg (or L) of formulated product per ha. It may also be useful to record the dose in g of active substance per ha. Deviations from the intended dosage should be noted.

2.3.5 *Data on other plant protection products*
If other plant protection products (or any biocontrol agents) have to be used, they should be applied uniformly to all plots, separately from the test product and reference product. Possible interference with these should be kept to a minimum.

3. Mode of assessment, recording and Measurements

3.1 *Meteorological and edaphic data*

3.1.1 *Meteorological data*
On the days before and after application, meteorological data should be recorded which is likely to affect the development of the crop and/or pest and the action of the plant protection product. This normally includes data on precipitation and temperature. All data should preferably be recorded on the trial site, but may be obtained from a nearby meteorological station. On the date of application, meteorological data should be recorded which is likely to affect the quality and persistence of the treatment. This normally includes at least precipitation (type and amount in mm) and
temperature (average, maximum, minimum in °C). Any significant change in weather should be noted, and in particular its time relative to the time of application. Because of the importance of climatic conditions for epidemiology of this disease, rainfall and temperature should be recorded throughout the trial period. In addition, any extreme weather conditions, such as severe or prolonged drought, heavy rain, late frosts, hail, etc., which are likely to influence the results, should also be reported. All data concerning irrigation should be recorded as appropriate.

3.1.2 *Edaphic data*
Not required.

3.2 *Type, time and frequency of assessment*

The BBCH growth stage of the crop at each date of application and assessment should be recorded.

3.2.1 *Type*
On leaves: samples of 100 leaves should be randomly selected from each plot and the percentage area on each leaf occupied by downy mildew estimated. If infection is low in the untreated plot (e.g. less than 1% of leaves), spots should be counted on 100 random leaves or the percentage of leaves affected should be determined on at least 15 randomly selected shoots per plot. If infection is heavy in the untreated plot (e.g. above 30–40 %), the degree of infection should be assessed in the whole plot, at least by estimating the percentage area affected on both faces of the row. See Appendix I and Fig. 1 for scales that may be used. On fruits: at least 100 bunches should be examined per plot for trials with natural infection and at least 50 bunches per plot for trials with artificial inoculation. If infection is heavy in the untreated plot, the percentage area infected should be assessed in each bunch. If infection is light in the untreated plot, percentage infected bunches should be determined.

3.2.2 *Time and frequency*
1st assessment when first symptoms occur in the untreated control. 2nd assessment at the beginning of ripening. It may be useful to make additional assessments, especially between first and second assessments.

3.3 *Direct effects on the crop*

The crop should be examined for the presence of phytotoxic effects (or visible remains of the product; deposits on table grapes), and this should be noted. In addition, any positive effects should be noted. The type and extent of such effects on the crop should be recorded and, if there are no effects, this fact should also be recorded. Phytotoxicity should be scored as follows:

(1) if the effect can be counted or measured, it should be expressed in absolute figures;

(2) in other cases, the frequency and intensity of damage should be estimated. This may be done in either of two ways: each plot is scored for phytotoxicity by reference to a scale, or each treated plot is compared with an untreated plot and % phytotoxicity estimated.

In all cases, symptoms of damage to the crop should be accurately described (stunting, chlorosis, deformation, etc.). For further details, see EPPO

Standard PP 1/135 Phytotoxicity assessment which contains sections on individual crops. It may be useful to assess effects on oenological and organoleptic quality using appropriate methodology (see EPPO Standard on oenological testing, in preparation); such information may come from an additional trial. In particular, attention should be paid to palatability and flavour of table grapes.

3.4 *Effects on non-target organisms*

3.4.1 *Effects on other pests*
Any observed effects, positive or negative, on the incidence of other pests should be recorded.

3.4.2 *Effects on other non-target organisms*
Any observed effects, positive or negative, on naturally occurring or introduced pollinators or natural enemies should be recorded. Any observed effect, positive or negative, on adjacent or succeeding crops should be recorded. Any environmental effects should also be recorded, especially effects on wildlife.

3.5 *Quantitative and qualitative recording of yield*

The fruits harvested in the various plots may be weighed but extrapolation of the data is only valid if the vineyard is homogeneous.

4. Results

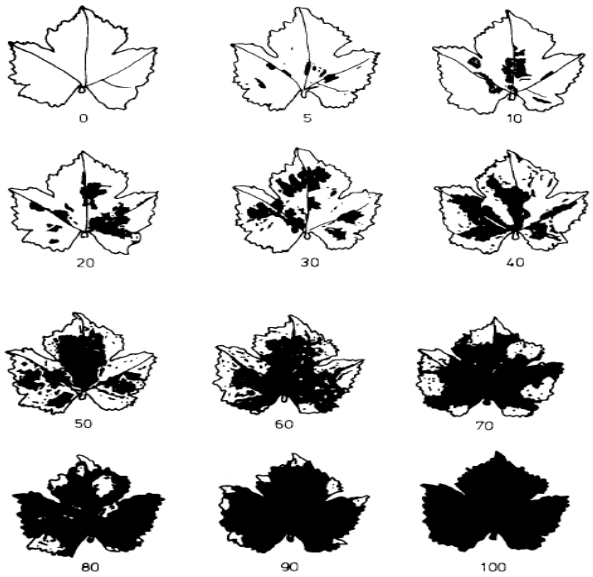
The results should be reported in a systematic form and the report should include an analysis and evaluation. Original (raw) data should be available. Statistical analysis should normally be used, by appropriate methods which should be indicated. If statistical analysis is not used, this should be justified. See EPPO Standard PP 1/152 Design and analysis of efficacy evaluation trials.

Appendix I

To assess percentage of leaf surface and bunch area affected, a scale such as the following may be used and should be described:

1 = no disease;
2 = <5%;
3 = 5-10%;
4 = 10-25%;
5 = 25-50%;
6 = 50-75%;
7 = >75%.

Fig. 1 *Plasmopara viticola*: percentage of lower leaf surface affected



6.3 Evaluation Form

Auswerteformular

Krems,

Botrytis	Penicillium	Essigfäule
Peronospora	Schwarzfäule	Oidium
Sonnenbrand	Stiellähme	Traubenwelke

Traubenbefall	1	2	3	4	5	6	7
Variante	0%	0-5 %	6- 10 %	11- 25 %	26-50 %	51-75 %	>75 %

Traubenbefall	1	2	3	4	5	6	7
Variante	0%	0-5 %	6- 10 %	11- 25 %	26-50 %	51-75 %	>75 %

Traubenbefall	1	2	3	4	5	6	7
Variante	0%	0-5 %	6- 10 %	11- 25 %	26-50 %	51-75 %	>75 %

Traubenbefall	1	2	3	4	5	6	7
Variante	0%	0-5 %	6- 10 %	11- 25 %	26-50 %	51-75 %	>75 %

auswerteformular_befallsgrad Seitennummer - -

6.4 BBCH-Scale for Grapevine

Growth stage	Code	Description
0: Sprouting/Bud development	00	Dormancy: winter buds pointed to rounded, light or dark brown according to cultivar; bud scales more or less closed according to cultivar
	01	Beginning of bud swelling: buds begin to expand inside the bud scales
	03	End of bud swelling: buds swollen, but not green
	05	"Wool stage": brown wool clearly visible
	07	Beginning of bud burst: green shoot tips just visible
	09	Bud burst: green shoot tips clearly visible
1: Leaf development	11	First leaf unfolded and spread away from shoot
	12	2nd leaves unfolded
	13	3rd leaves unfolded
	19	9 or more leaves unfolded
5: Inflorescence emerge	53	Inflorescences clearly visible
	55	Inflorescences swelling, flowers closely pressed together
	57	Inflorescences fully developed; flowers separating
6: Flowering	60	First flowerhoods detached from the receptacle
	61	Beginning of flowering: 10% of flowerhoods fallen
	62	20% of flowerhoods fallen
	63	Early flowering: 30% of flowerhoods fallen
	64	40% of flowerhoods fallen
	65	Full flowering: 50% of flowerhoods fallen
	66	60% of flowerhoods fallen
	67	70% of flowerhoods fallen
	68	80% of flowerhoods fallen
	69	End of flowering
7: Development of fruits	71	Fruit set: young fruits begin to swell, remains of flowers lost
	73	Berries groat-sized, bunches begin to hang
	75	Berries pea-sized, bunches hang
	77	Berries beginning to touch
	79	Majority of berries touching
8: Ripening of berries	81	Beginning of ripening: berries begin to develop variety-specific colour
	83	Berries developing colour
	85	Softening of berries
	89	Berries ripe for harvest
9: Senescence	91	After harvest; end of wood maturation

6.5 Powdery Mildew VitiMeteo Prognostic Data

ViTiMeteo
Agroscope
Staatliches Weinbauinstitut Freiburg
GEOsens Softwareentwicklung

Prognose für Oidium und Rebwachstum

Eine Gemeinschaftsentwicklung von Agroscope Changins- Wädenswil und Staatlichem Weinbauinstitut Freiburg (D)
Berechnung: Oidium nach Oidiag 2.2, Dr. Walter Kast, LVWO Weinsberg; Rebwachstum nach Prof. Dr. H. Schultz, FA Geisenheim

Station: Krems-Landersdorf, 01.01.2016 - 01.10.2016

Erstellt: 26.09.2016 12:54:38 Wetterdaten bis: 26.09.2016 11:15 Vorhersage bis: 01.10.2016 11:00

Austrieb: 20.04.2016 00:00 Wachstum angegeben für: Durschschnittsrebsorte pro Haupttrieb (ohne Geiztriebe)

Datum	Oidium-Index	Risiko	Temperatur °C Min	Ø	Max	Niederschlag mm	Wachstum Blattzahl	Blattfläche cm²	Bemerkungen
01.01.2016	0 %	!	-3,3	-1,0	3,3	0,4	0	0	
02.01.2016	0 %	!	-3,9	-1,7	0,7	0,0	0	0	
03.01.2016	0 %	!	-5,7	-5,1	-4,0	0,0	0	0	
04.01.2016	0 %	!	-7,5	-5,8	-4,6	0,0	0	0	
05.01.2016	0 %	!	-10,2	-6,2	-4,1	0,0	0	0	
06.01.2016	0 %	!	-5,9	-4,3	-2,4	0,0	0	0	
07.01.2016	0 %	!	-8,5	-2,2	2,5	2,0	0	0	
08.01.2016	0 %	!	-6,4	1,2	9,4	0,2	0	0	
09.01.2016	0 %	!	-2,4	0,2	1,8	1,8	0	0	
10.01.2016	0 %	!	0,0	0,9	1,9	2,0	0	0	
11.01.2016	0 %	!	0,4	2,7	7,6	0,2	0	0	
12.01.2016	0 %	!	-1,9	5,6	9,6	0,0	0	0	
13.01.2016	0 %	!	3,2	5,3	8,0	0,0	0	0	
14.01.2016	0 %	!	-3,3	2,4	8,4	0,0	0	0	
15.01.2016	0 %	!	-2,0	1,9	5,4	0,0	0	0	
16.01.2016	0 %	!	-3,3	0,3	1,6	0,0	0	0	
17.01.2016	0 %	!	-8,4	-2,7	-0,6	0,0	0	0	
18.01.2016	0 %	!	-9,9	-4,6	0,9	0,8	0	0	
19.01.2016	0 %	!	-11,4	-7,7	-1,7	0,0	0	0	
20.01.2016	0 %	!	-13,0	-4,9	2,0	0,0	0	0	
21.01.2016	0 %	!	-8,6	-2,6	0,8	0,0	0	0	
22.01.2016	0 %	!	-11,9	-7,3	-1,1	0,0	0	0	
23.01.2016	0 %	!	-11,9	-6,9	-0,3	0,0	0	0	
24.01.2016	0 %	!	-2,8	1,7	7,6	3,2	0	0	
25.01.2016	0 %	!	-2,4	3,3	6,1	3,4	0	0	
26.01.2016	0 %	!	-2,4	3,8	11,7	0,0	0	0	
27.01.2016	0 %	!	-3,4	2,0	10,3	0,0	0	0	
28.01.2016	0 %	!	2,1	7,7	17,5	0,0	0	0	
29.01.2016	0 %	!	-2,0	4,6	11,9	6,0	0	0	
30.01.2016	0 %	!	-3,7	3,0	13,1	0,0	0	0	
31.01.2016	0 %	!	0,2	5,3	8,9	0,0	0	0	
01.02.2016	0 %	!	2,8	8,5	14,9	4,0	0	0	
02.02.2016	0 %	!	0,1	8,1	13,3	0,0	0	0	
03.02.2016	0 %	!	0,5	5,9	10,5	5,2	0	0	
04.02.2016	0 %	!	-1,4	3,4	6,8	0,0	0	0	
05.02.2016	0 %	!	-1,1	3,8	8,8	0,0	0	0	

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Austrieb: 20.04.2016 00:00 Wachstum angegeben für: Durschschnittsrebsorte pro Haupttrieb (ohne Geiztriebe)

Datum	Oidium-Index	Risiko	Temperatur °C			Niederschlag	Wachstum		Bemerkungen
			Min	Ø	Max	mm	Blattzahl	Blattfläche cm²	
06.02.2016	0 %	!	-3,4	3,4	10,4	0,0	0	0	
07.02.2016	0 %	!	1,0	3,9	11,2	0,0	0	0	
08.02.2016	0 %	!	2,4	6,7	11,8	0,0	0	0	
09.02.2016	0 %	!	2,4	8,0	14,8	0,2	0	0	
10.02.2016	0 %	!	3,7	5,1	9,0	0,0	0	0	
11.02.2016	0 %	!	-3,8	3,4	8,0	0,0	0	0	
12.02.2016	0 %	!	-5,8	0,4	6,6	0,0	0	0	
13.02.2016	0 %	!	-0,8	3,2	9,5	0,0	0	0	
14.02.2016	0 %	!	-0,4	3,3	6,1	0,0	0	0	
15.02.2016	0 %	!	2,8	5,9	8,8	0,0	0	0	
16.02.2016	0 %	!	-0,1	4,3	7,7	0,0	0	0	
17.02.2016	0 %	!	1,2	2,6	4,4	0,8	0	0	
18.02.2016	0 %	!	2,4	3,7	4,9	4,8	0	0	
19.02.2016	0 %	!	2,0	4,5	7,8	4,0	0	0	
20.02.2016	0 %	!	1,9	5,5	9,8	1,0	0	0	
21.02.2016	0 %	!	4,3	11,4	14,8	1,8	0	0	
22.02.2016	0 %	!	5,9	13,3	20,2	0,0	0	0	
23.02.2016	0 %	!	3,3	10,7	15,3	0,2	0	0	
24.02.2016	0 %	!	-3,7	2,2	8,3	0,0	0	0	
25.02.2016	0 %	!	-5,1	1,4	5,3	0,0	0	0	
26.02.2016	0 %	!	-2,8	1,6	8,3	0,0	0	0	
27.02.2016	0 %	!	-4,0	2,7	8,9	0,0	0	0	
28.02.2016	0 %	!	-0,1	5,9	12,4	0,0	0	0	
29.02.2016	0 %	!	4,9	5,8	7,0	10,6	0	0	
01.03.2016	0 %	!	0,2	3,1	5,3	0,2	0	0	
02.03.2016	0 %	!	-3,7	3,5	10,8	0,0	0	0	
03.03.2016	0 %	!	2,1	4,5	7,2	1,2	0	0	
04.03.2016	0 %	!	0,0	4,0	10,3	0,0	0	0	
05.03.2016	0 %	!	-0,7	3,5	9,4	0,0	0	0	
06.03.2016	0 %	!	1,3	5,4	9,8	0,0	0	0	
07.03.2016	0 %	!	0,6	3,4	7,6	1,0	0	0	
08.03.2016	0 %	!	-1,4	3,2	6,8	0,0	0	0	
09.03.2016	0 %	!	-4,0	1,1	7,1	0,0	0	0	
10.03.2016	0 %	!	-1,4	5,0	11,8	0,0	0	0	
11.03.2016	0 %	!	4,8	5,8	6,9	0,0	0	0	
12.03.2016	0 %	!	3,9	5,8	7,9	0,0	0	0	
13.03.2016	0 %	!	3,7	5,4	6,8	0,0	0	0	
14.03.2016	0 %	!	-1,7	3,9	10,5	0,0	0	0	
15.03.2016	0 %	!	-0,2	2,5	7,0	4,6	0	0	
16.03.2016	0 %	!	-1,4	2,8	6,9	2,0	0	0	

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Austrieb: 20.04.2016 00:00 Wachstum angegeben für: Durschschnittsrebsorte pro Haupttrieb (ohne Geiztriebe)

Datum	Oidium-Index	Risiko	Temperatur °C			Niederschlag	Wachstum		Bemerkungen
			Min	Ø	Max	mm	Blattzahl	Blattfläche cm²	
17.03.2016	0 %	!	-3,9	4,2	12,5	0,0	0	0	
18.03.2016	0 %	!	-2,3	7,0	17,2	0,0	0	0	
19.03.2016	0 %	!	-0,4	5,6	10,1	0,0	0	0	
20.03.2016	0 %	!	4,1	8,0	14,0	0,0	0	0	
21.03.2016	0 %	!	4,9	8,1	12,4	0,0	0	0	
22.03.2016	0 %	!	3,4	6,7	10,8	0,4	0	0	
23.03.2016	0 %	!	1,2	6,0	9,9	0,0	0	0	
24.03.2016	0 %	!	2,5	6,0	11,1	0,0	0	0	
25.03.2016	0 %	!	2,2	6,7	11,2	0,0	0	0	
26.03.2016	0 %	!	1,6	6,8	9,9	0,4	0	0	
27.03.2016	0 %	!	-0,7	7,9	16,3	0,0	0	0	
28.03.2016	0 %	!	2,3	9,1	17,1	0,0	0	0	
29.03.2016	0 %	!	1,1	9,9	17,1	0,0	0	0	
30.03.2016	0 %	!	5,0	11,8	20,1	0,0	0	0	
31.03.2016	0 %	!	3,4	14,2	23,8	0,4	0	0	
01.04.2016	0 %	!	3,0	9,2	15,0	0,0	0	0	
02.04.2016	0 %	!	-0,2	8,5	16,6	0,0	0	0	
03.04.2016	0 %	!	3,2	11,8	20,9	0,0	0	0	
04.04.2016	0 %	!	5,2	14,2	23,6	0,0	0	0	
05.04.2016	0 %	!	7,7	15,8	24,3	0,0	0	0	
06.04.2016	0 %	!	9,7	14,0	17,8	0,0	0	0	
07.04.2016	0 %	!	8,6	12,0	16,0	0,8	0	0	
08.04.2016	0 %	!	7,3	9,2	11,1	12,8	0	0	
09.04.2016	0 %	!	7,4	8,0	9,7	0,6	0	0	
10.04.2016	0 %	!	2,8	8,7	12,1	0,0	0	0	
11.04.2016	0 %	!	1,4	8,8	14,7	0,0	0	0	
12.04.2016	0 %	!	4,6	11,9	17,3	0,0	0	0	
13.04.2016	0 %	!	3,6	12,6	21,1	7,0	0	0	
14.04.2016	0 %	!	6,2	10,6	15,0	4,0	0	0	
15.04.2016	0 %	!	1,8	10,1	18,1	0,0	0	0	
16.04.2016	0 %	!	6,4	14,1	21,8	0,0	0	0	
17.04.2016	0 %	!	6,1	14,1	23,0	2,4	0	0	
18.04.2016	0 %	!	8,2	10,6	13,5	5,2	0	0	
19.04.2016	0 %	!	6,7	11,3	16,7	0,0	1	4	
20.04.2016	0 %	!	4,1	10,8	16,9	0,0	1	4	
21.04.2016	0 %	!	0,4	9,7	18,0	0,0	1	4	
22.04.2016	0 %	!	2,0	12,2	21,7	0,0	1	4	
23.04.2016	0 %	!	5,4	11,1	16,7	0,4	1	5	
24.04.2016	0 %	!	0,8	6,3	10,2	3,2	1	5	
25.04.2016	0 %	!	-1,2	4,1	10,3	0,0	1	5	

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Datum	Oidium-Index	Risiko	Temperatur °C			Nieder-schlag	Wachstum		Bemerkungen
			Min	Ø	Max	mm	Blatt-zahl	Blatt-fläche cm²	
26.04.2016	0 %	!	-2,7	6,8	16,3	0,0	1	5	
27.04.2016	0 %	!	-0,3	5,2	7,8	2,0	1	5	
28.04.2016	0 %	!	-3,6	6,0	14,1	0,0	1	5	
29.04.2016	0 %	!	-2,5	7,6	16,5	0,0	1	5	
30.04.2016	0 %	!	0,5	11,2	20,0	0,0	1	5	
01.05.2016	0 %	!	2,2	11,3	17,2	0,0	1	5	
02.05.2016	0 %	!	10,1	13,4	18,4	0,2	1	6	
03.05.2016	0 %	!	8,3	12,5	19,2	1,0	1	7	
04.05.2016	0 %	!	7,8	9,1	10,5	5,2	1	7	
05.05.2016	0 %	!	7,1	11,2	18,5	2,4	1	8	
06.05.2016	0 %	!	4,1	13,9	22,3	0,0	2	13	
07.05.2016	0 %	!	5,6	15,3	23,3	0,0	2	20	
08.05.2016	0 %	!	6,2	14,4	21,4	0,0	2	24	
09.05.2016	0 %	!	4,0	15,3	22,8	0,0	2	28	
10.05.2016	0 %	!	10,0	14,9	20,6	0,0	3	41	
11.05.2016	0 %	!	10,9	15,1	20,8	0,0	3	55	
12.05.2016	0 %	!	13,2	14,0	15,2	10,8	3	65	
13.05.2016	0 %	!	10,7	12,9	15,3	36,8	3	76	
14.05.2016	0 %	!	11,8	15,5	21,3	3,0	4	100	
15.05.2016	0 %	!	5,3	10,4	14,2	0,0	4	100	
16.05.2016	0 %	!	1,8	8,9	14,8	0,6	4	100	
17.05.2016	0 %	!	5,8	10,3	14,7	0,0	4	101	
18.05.2016	0 %	!	6,5	12,8	20,0	0,0	4	113	
19.05.2016	0 %	!	5,3	13,6	20,6	0,0	4	127	
20.05.2016	0 %	!	9,1	14,6	19,5	0,8	4	149	
21.05.2016	7 %	!	5,6	16,3	24,9	0,0	5	178	
22.05.2016	14 %	!	8,8	19,1	27,6	0,0	5	224	
23.05.2016	22 %	!	10,2	17,6	26,4	2,4	5	274	
24.05.2016	27 %	!	9,5	12,3	17,4	7,0	6	294	
25.05.2016	36 %	!!	11,4	15,5	22,1	0,0	6	350	
26.05.2016	44 %	!!	7,5	16,9	25,6	0,0	6	398	
27.05.2016	54 %	!!	10,2	18,1	26,0	0,0	7	455	
28.05.2016	56 %	!!	13,5	21,4	28,9	0,4	7	558	
29.05.2016	61 %	!!	17,0	21,5	27,6	0,0	8	671	
30.05.2016	64 %	!!	11,7	19,1	26,1	0,0	8	752	
31.05.2016	70 %	!!!	11,1	18,9	24,9	0,2	9	829	
01.06.2016	73 %	!!!	10,7	16,8	22,5	0,0	9	888	
02.06.2016	77 %	!!!	9,8	16,8	23,4	0,0	9	959	
03.06.2016	81 %	!!!	13,9	18,0	23,4	9,8	10	1045	
04.06.2016	86 %	!!!	11,9	18,9	25,2	0,0	10	1124	

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Datum	Oidium-Index	Risiko	Temperatur °C			Nieder-schlag	Wachstum		Bemerkungen
			Min	Ø	Max	mm	Blatt-zahl	Blatt-fläche cm²	
05.06.2016	86 %	!!!	14,2	18,3	24,7	7,4	10	1224	
06.06.2016	89 %	!!!	10,6	18,1	26,0	7,0	11	1299	
07.06.2016	90 %	!!!	9,7	18,0	24,0	0,0	11	1365	
08.06.2016	90 %	!!!	9,5	18,4	25,7	0,0	11	1436	
09.06.2016	94 %	!!!	10,8	17,7	23,8	0,4	12	1497	
10.06.2016	95 %	!!!	13,5	19,6	25,5	0,4	12	1579	
11.06.2016	92 %	!!!	11,3	17,1	23,3	3,2	12	1635	
12.06.2016	93 %	!!!	13,6	16,6	21,5	4,2	13	1697	
13.06.2016	94 %	!!!	13,3	18,3	23,2	0,8	13	1764	
14.06.2016	97 %	!!!	11,1	17,9	24,6	0,0	13	1819	
15.06.2016	86 %	!!!	12,6	16,4	22,7	10,6	14	1870	
16.06.2016	86 %	!!!	11,0	20,3	28,3	0,0	14	1948	
17.06.2016	86 %	!!!	11,6	18,7	22,7	0,0	14	1994	
18.06.2016	90 %	!!!	11,8	18,4	25,9	0,0	15	2056	
19.06.2016	94 %	!!!	10,9	18,1	25,1	0,4	15	2104	
20.06.2016	78 %	!!!	12,8	16,2	19,0	12,2	15	2145	
21.06.2016	77 %	!!!	11,2	18,9	26,5	0,0	16	2203	
22.06.2016	91 %	!!!	13,5	20,9	27,8	0,0	16	2263	
23.06.2016	89 %	!!!	15,0	23,5	30,1	0,0	17	2341	
24.06.2016	87 %	!!!	15,9	25,4	32,5	0,0	17	2415	
25.06.2016	85 %	!!!	19,2	26,3	32,3	0,0	18	2497	
26.06.2016	82 %	!!!	18,7	21,6	26,6	0,0	18	2562	
27.06.2016	92 %	!!!	12,3	17,3	22,2	12,8	18	2602	
28.06.2016	87 %	!!!	11,8	20,0	26,8	0,0	19	2643	
29.06.2016	83 %	!!!	11,6	21,7	29,6	0,0	19	2689	
30.06.2016	79 %	!!!	18,1	23,7	30,5	1,2	20	2757	
01.07.2016	73 %	!!!	14,3	22,0	29,6	4,4	20	2806	
02.07.2016	70 %	!!!	14,2	21,5	31,3	7,0	20	2861	
03.07.2016	66 %	!!!	14,1	18,1	22,9	2,0	21	2893	
04.07.2016	63 %	!!	13,0	19,7	26,0	0,0	21	2930	
05.07.2016	62 %	!!	11,2	21,2	28,4	0,0	21	2965	
06.07.2016	54 %	!!	12,1	20,1	25,5	0,0	22	3002	
07.07.2016	47 %	!!	10,1	18,6	26,2	0,0	22	3029	
08.07.2016	43 %	!!	9,2	20,2	28,5	0,0	22	3060	
09.07.2016	36 %	!!	16,5	21,6	28,9	0,0	23	3101	
10.07.2016	31 %	!	13,2	22,9	31,2	0,0	23	3141	
11.07.2016	26 %	!	15,4	25,3	35,9	0,0	24	3192	
12.07.2016	18 %	!	17,6	22,0	31,7	42,2	24	3228	
13.07.2016	18 %	!	16,8	19,2	25,2	6,6	24	3266	
14.07.2016	19 %	!	11,4	15,4	19,2	4,0	24	3283	

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Datum	Oidium-Index	Risiko	Temperatur °C			Niederschlag	Wachstum		Bemerkungen
			Min	Ø	Max	mm	Blattzahl	Blattfläche cm²	
15.07.2016	18 %	!	10,0	16,2	22,5	0,0	25	3299	
16.07.2016	17 %	!	13,3	16,3	20,2	0,0	25	3315	
17.07.2016	18 %	!	12,8	17,9	24,8	0,8	25	3338	
18.07.2016	18 %	!	14,3	22,5	29,1	0,0	25	3372	
19.07.2016	21 %	!	12,9	22,2	29,9	0,0	26	3398	
20.07.2016	21 %	!	15,2	22,8	31,1	0,0	26	3424	
21.07.2016	21 %	!	13,0	22,4	31,6	0,0	27	3461	
22.07.2016	21 %	!	16,4	23,2	31,7	0,0	27	3488	
23.07.2016	22 %	!	18,1	24,0	31,8	1,4	27	3524	
24.07.2016	21 %	!	18,1	23,6	31,6	19,2	28	3554	
25.07.2016	21 %	!	16,6	23,5	31,8	0,0	28	3576	
26.07.2016	21 %	!	17,2	22,7	32,6	0,4	28	3611	
27.07.2016	21 %	!	16,9	23,5	31,8	0,0	29	3633	
28.07.2016	21 %	!	16,1	21,6	30,0	3,8	29	3656	
29.07.2016	21 %	!	13,6	22,1	31,0	0,0	29	3680	
30.07.2016	21 %	!	13,8	24,1	33,7	0,0	30	3697	
31.07.2016	22 %	!	16,6	22,8	34,4	4,2	30	3723	
01.08.2016	22 %	!	13,1	20,5	27,1	0,0	30	3739	
02.08.2016	22 %	!	10,0	20,3	29,4	0,0	31	3750	
03.08.2016	22 %	!	16,9	22,6	32,0	0,0	31	3767	
04.08.2016	22 %	!	14,6	23,6	32,0	0,0	31	3789	
05.08.2016	19 %	!	14,9	18,3	25,5	12,4	31	3798	
06.08.2016	19 %	!	13,8	19,1	28,9	0,0	32	3805	
07.08.2016	19 %	!	10,1	19,9	28,7	0,0	32	3821	
08.08.2016	19 %	!	10,3	21,1	31,4	0,0	32	3835	
09.08.2016	20 %	!	12,6	17,8	29,8	5,4	32	3842	
10.08.2016	17 %	!	11,3	14,6	17,9	16,0	32	3844	
11.08.2016	16 %	!	5,9	14,0	25,2	0,0	32	3849	
12.08.2016	18 %	!	6,1	14,1	23,3	0,0	32	3851	
13.08.2016	18 %	!	12,5	19,4	28,3	0,0	33	3866	
14.08.2016	18 %	!	10,6	21,3	32,8	0,0	33	3876	
15.08.2016	18 %	!	13,4	20,3	29,9	0,0	33	3883	
16.08.2016	18 %	!	12,1	19,7	29,0	0,0	33	3886	
17.08.2016	22 %	!	11,0	19,0	28,5	0,0	33	3889	
18.08.2016	22 %	!	7,8	18,6	30,2	0,0	33	3901	
19.08.2016	22 %	!	11,5	18,4	30,2	0,4	33	3908	
20.08.2016	22 %	!	11,6	20,4	30,3	0,0	34	3913	
21.08.2016	22 %	!	15,0	18,0	23,8	7,4	34	3915	
22.08.2016	22 %	!	10,9	17,6	25,7	0,2	34	3916	
23.08.2016	22 %	!	7,9	18,5	32,5	0,0	34	3917	

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Station: Krems-Landersdorf, 01.01.2016 - 01.10.2016

Erstellt: 26.09.2016 12:54:38 Wetterdaten bis: 26.09.2016 11:15 Vorhersage bis: 01.10.2016 11:00

Austrieb: 20.04.2016 00:00 Wachstum angegeben für: Durschschnittsrebsorte pro Haupttrieb (ohne Geiztriebe)

Datum	Oidium-Index	Risiko	Temperatur °C			Niederschlag	Wachstum		Bemerkungen
			Min	Ø	Max	mm	Blattzahl	Blattfläche cm²	
24.08.2016	22 %	!	10,7	20,3	30,8	0,0	34	3919	
25.08.2016	22 %	!	9,3	19,2	30,1	0,0	34	3925	
26.08.2016	22 %	!	8,6	19,8	30,9	0,0	34	3928	
27.08.2016	22 %	!	10,9	21,6	34,1	0,0	34	3930	
28.08.2016	22 %	!	13,4	23,3	34,7	0,0	34	3931	
29.08.2016	22 %	!	15,2	20,4	31,5	4,0	34	3931	
30.08.2016	22 %	!	11,5	19,8	31,5	0,0	34	3931	
31.08.2016	19 %	!	7,0	17,6	28,9	0,0	34	3931	
01.09.2016	16 %	!	8,5	19,9	32,0	0,0	34	3931	
02.09.2016	13 %	!	10,9	19,4	32,5	5,4	34	3931	
03.09.2016	9 %	!	10,4	19,7	31,4	0,0	34	3931	
04.09.2016	6 %	!	11,9	21,1	32,1	0,0	34	3931	
05.09.2016	3 %	!	14,9	17,7	23,4	7,6	34	3931	
06.09.2016	0 %	!	13,2	15,0	16,3	4,0	34	3931	
07.09.2016	0 %	!	14,7	19,1	27,2	0,0	34	3931	
08.09.2016	0 %	!	10,4	19,5	28,9	0,0	34	3931	
09.09.2016	0 %	!	11,3	21,0	32,4	0,0	34	3931	
10.09.2016	0 %	!	12,4	21,0	30,9	0,0	34	3931	
11.09.2016	0 %	!	12,3	21,6	32,8	0,0	34	3931	
12.09.2016	0 %	!	14,0	21,9	31,5	0,0	34	3931	
13.09.2016	0 %	!	12,4	21,4	31,1	0,0	34	3931	
14.09.2016	0 %	!	12,8	20,1	29,1	0,0	34	3931	
15.09.2016	0 %	!	10,3	19,7	29,2	0,0	34	3931	
16.09.2016	0 %	!	12,9	20,4	30,0	0,0	34	3931	
17.09.2016	0 %	!	14,7	17,0	20,2	1,0	34	3931	
18.09.2016	0 %	!	14,4	16,8	21,2	0,0	34	3931	
19.09.2016	0 %	!	10,9	16,1	21,2	0,0	34	3931	
20.09.2016	0 %	!	9,5	13,9	20,0	1,6	34	3931	
21.09.2016	0 %	!	6,0	12,3	21,2	0,0	34	3931	
22.09.2016	0 %	!	6,3	13,5	21,7	0,0	34	3931	
23.09.2016	0 %	!	3,0	12,7	23,8	0,0	34	3931	
24.09.2016	0 %	!	3,3	13,7	24,8	0,0	34	3931	
25.09.2016	0 %	!	3,9	13,7	24,3	0,0	34	3931	
26.09.2016	0 %	!	5,9	10,7	18,2	0,0	34	3931	
27.09.2016	0 %	!	9,4	14,3	20,2	0,0	34	3931	
28.09.2016	0 %	!	9,5	14,1	22,9	0,0	34	3931	
29.09.2016	0 %	!	14,1	18,7	23,9	0,0	34	3931	
30.09.2016	0 %	!	13,9	18,5	25,3	0,0	34	3931	

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Station: Krems-Landersdorf, 01.01.2016 - 01.10.2016

Erstellt: 26.09.2016 12:54:38 Wetterdaten bis: 26.09.2016 11:15 Vorhersage bis: 01.10.2016 11:00

Austrieb: 20.04.2016 00:00 Wachstum angegeben für Durschschnittsrebsorte pro Haupttrieb (ohne Geiztriebe)

Datum	Oidium-Index	Risiko	Temperatur °C Min	Ø	Max	Niederschlag mm	Wachstum Blattzahl	Blattfläche cm²	Bemerkungen

Erster Spritztermin auf Basis der Bewertung des Vorjahresbefalls in den entsprechenden Rebanlagen und den bisherigen Versuchsergebnissen der Forschungseinrichtungen:

Boniturwert	Befallsstärke	erster Behandlungstermin
0	Keinerlei Funde von Oidium	Mit der ersten Behandlung gegen Rebenperonospora spätestens zw. dem 6- und 9 Blattstadium
1	An einzelnen Blättern geringer Spätbefall	
2	In einzelnen Anlagen Spätbefall	
3	Verbreitet Spätbefall an den Blättern und Geiztrauben in den meisten Anlagen	
4	Vereinzelte Schäden an Trauben	Zwischen dem 3- und 6-Blattstadium
5	In mehr als 5 % der Anlagen Traubenbefall	

Grau hinterlegt: Daten aus Wettervorhersage (sofern vorhanden).

OidiumIndex: ! geringes Risiko !! mittel !!! hoch

Realisierung und Programmierung: Geosens Software- und Messsystementwicklung, www.geosens.com

6.6 Downy Mildew VitiMeteo Prognostic Data

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Detaillierte Prognose für Plasmopara viticola und Rebwachstum

Eine Gemeinschaftsentwicklung von Agroscope CH (RAC Changins, FAW Wädenswil) und Staatl. Weinbauinstitut Freiburg (D)
Berechnung: Sporangiendichte nach Dr. G. Hill, DLR Oppenheim; Rebwachstum nach Prof. Dr. H. Schultz, FA Geisenheim

Station: Krems-Landersdorf, 01.01.2016 - 01.10.2016

Erstellt: 26.09.2016 12:06:48 Wetterdaten bis: 26.09.2016 11:15 Vorhersage bis: 01.10.2016 11:00

Keimbereitschaft: 11.05.2016
Austrieb: 20.04.2016

Wachstum angegeben für: pro Haupttrieb (ohne Geiztriebe)

Durchschnittsrebsorte

Datum	Sporulation	Sporangiendichte	Infektion	Inkubation 26.09.	Inkubation 01.10.	Temperatur °C Min.	Temperatur °C Ø	Temperatur °C Max.	Niederschlag mm	Blattnässe Grad-std. bei Std.	Blattnässe Grad-std. bei BN.	Wachstum Blattzahl	Wachstum Blattfläche cm²	Bemerkungen
01.01.						-3,3	-1,0	3,3	0,4	3				
02.01.						-3,9	-1,7	0,7		2				
03.01.						-5,7	-5,1	-4,0						
04.01.						-7,5	-5,8	-4,6						
05.01.						-10,2	-6,2	-4,1						
06.01.						-5,9	-4,3	-2,4						
07.01.						-8,5	-2,2	2,5	2,0	1				
08.01.						-6,4	1,2	9,4	0,2	3	15			
09.01.						-2,4	0,2	1,8	1,8	10	5			
10.01.						0,0	0,9	1,9	2,0	16	6			
11.01.						0,4	2,7	7,6	0,2	11	10			
12.01.						-1,9	5,6	9,6		2	6			
13.01.						3,2	5,3	8,0		2	4			
14.01.						-3,3	2,4	8,4		2	3			
15.01.						-2,0	1,9	5,4			1			
16.01.						-3,3	0,3	1,6						
17.01.						-8,4	-2,7	-0,6		10				
18.01.						-9,9	-4,6	0,9	0,8	10				
19.01.						-11,4	-7,7	-1,7						
20.01.						-13,0	-4,9	2,0						
21.01.						-8,6	-2,6	0,8						
22.01.						-11,9	-7,3	-1,1						
23.01.						-11,9	-6,9	-0,3		15				
24.01.						-2,8	1,7	7,6	3,2	7	2			
25.01.						-2,4	3,3	6,1	3,4	18	50			
26.01.						-2,4	3,8	11,7						
27.01.						-3,4	2,0	10,3		4	15			
28.01.						2,1	7,7	17,5		1	4			
29.01.						-2,0	4,6	11,9	6,0	12	36			
30.01.						-3,7	3,0	13,1		3	19			
31.01.						0,2	5,3	8,9		9	17			
01.02.						2,8	8,5	14,9	4,0	11	44			
02.02.						0,1	8,1	13,3						
03.02.						0,5	5,9	10,5	5,2	11	19			

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Station: Krems-Landersdorf, 01.01.2016 - 01.10.2016

Erstellt: 26.09.2016 12:06:48 Wetterdaten bis: 26.09.2016 11:15 Vorhersage bis: 01.10.2016 11:00

Keimbereitschaft: 11.05.2016
Austrieb: 20.04.2016

Wachstum angegeben für: Durchschnittsrebsorte
pro Haupttrieb (ohne Geiztriebe)

Datum	Sporulation	Sporangiendichte	Infektion	Inkubation 26.09.	Inkubation 01.10.	Temperatur °C Min.	Temperatur °C Ø	Temperatur °C Max.	Niederschlag mm	Blattnässe Grad-std. Std.	Blattnässe bei BN.	Wachstum Blattzahl	Wachstum Blattfläche cm²	Bemerkungen
04.02.						-1,4	3,4	6,8		2	28			
05.02.						-1,1	3,8	8,8		3	8			
06.02.						-3,4	3,4	10,4		5	11			
07.02.						1,0	3,9	11,2						
08.02.						2,4	6,7	11,8		2	7			
09.02.						2,4	8,0	14,8	0,2	10	63			
10.02.						3,7	5,1	9,0		7	19			
11.02.						-3,8	3,4	8,0		2	5			
12.02.						-5,8	0,4	6,6		2	7			
13.02.						-0,8	3,2	9,5						
14.02.						-0,4	3,3	6,1		3	14			
15.02.						2,8	5,9	8,8						
16.02.						-0,1	4,3	7,7						
17.02.						1,2	2,6	4,4	0,8	11	22			
18.02.						2,4	3,7	4,9	4,8	12	50			
19.02.						2,0	4,5	7,8	4,0	11	26			
20.02.						1,9	5,5	9,8	1,0	3	16			
21.02.						4,3	11,4	14,8	1,8	5	11			
22.02.						5,9	13,3	20,2						
23.02.						3,3	10,7	15,3	0,2	5	20			
24.02.						-3,7	2,2	8,3		3	27			
25.02.						-5,1	1,4	5,3			1			
26.02.						-2,8	1,6	8,3						
27.02.						-4,0	2,7	8,9						
28.02.						-0,1	5,9	12,4						
29.02.						4,9	5,8	7,0	10,6	14	45			
01.03.						0,2	3,1	5,3	0,2	7	16			
02.03.						-3,7	3,5	10,8		3	4			
03.03.						2,1	4,5	7,2	1,2	7	18			
04.03.						0,0	4,0	10,3		4	16			
05.03.						-0,7	3,5	9,4						
06.03.						1,3	5,4	9,8						
07.03.						0,6	3,4	7,6	1,0	4	11			
08.03.						-1,4	3,2	6,8		6	17			
09.03.						-4,0	1,1	7,1		3	3			
10.03.						-1,4	5,0	11,8		7	3			
11.03.						4,8	5,8	6,9		10	19			

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Station: Krems-Landersdorf, 01.01.2016 - 01.10.2016

Erstellt: 26.09.2016 12:06:48 Wetterdaten bis: 26.09.2016 11:15 Vorhersage bis: 01.10.2016 11:00

Keimbereitschaft: 11.05.2016
Austrieb: 20.04.2016

Wachstum angegeben für: Durchschnittsrebsorte
pro Haupttrieb (ohne Geiztriebe)

Datum	Sporulation	Sporangiendichte	Infektion	Inkubation 26.09.	Inkubation 01.10.	Temperatur °C Min.	Temperatur °C Ø	Temperatur °C Max.	Niederschlag mm	Blattnässe Std.	Blattnässe Grad-std. bei BN.	Wachstum Blattzahl	Wachstum Blattfläche cm²	Bemerkungen
12.03.						3,9	5,8	7,9		2	12			
13.03.						3,7	5,4	6,8		1	18			
14.03.						-1,7	3,9	10,5						
15.03.						-0,2	2,5	7,0	4,6	9	17			
16.03.						-1,4	2,8	6,9	2,0	11	21			
17.03.						-3,9	4,2	12,5		1	4			
18.03.						-2,3	7,0	17,2		2	4			
19.03.						-0,4	5,6	10,1						
20.03.						4,1	8,0	14,0						
21.03.						4,9	8,1	12,4						
22.03.						3,4	6,7	10,8	0,4	4	18			
23.03.						1,2	6,0	9,9		1	5			
24.03.						2,5	6,0	11,1		6	11			
25.03.						2,2	6,7	11,2		4	26			
26.03.						1,6	6,8	9,9	0,4	9	68			
27.03.						-0,7	7,9	16,3						
28.03.						2,3	9,1	17,1						
29.03.						1,1	9,9	17,1						
30.03.						5,0	11,8	20,1		1	9			
31.03.						3,4	14,2	23,8	0,4	10	105			
01.04.						3,0	9,2	15,0						
02.04.						-0,2	8,5	16,6						
03.04.						3,2	11,8	20,9						
04.04.						5,2	14,2	23,6						
05.04.						7,7	15,8	24,3						
06.04.						9,7	14,0	17,8						
07.04.						8,6	12,0	16,0	0,8	16	112			
08.04.						7,3	9,2	11,1	12,8	10	45			
09.04.						7,4	8,0	9,7	0,6	4	13			
10.04.						2,8	8,7	12,1						
11.04.						1,4	8,8	14,7		6	20			
12.04.						4,6	11,9	17,3						
13.04.						3,6	12,6	21,1	7,0	10	48			
14.04.						6,2	10,6	15,0	4,0	7	47			
15.04.						1,8	10,1	18,1		6	20			
16.04.						6,4	14,1	21,8						
17.04.						6,1	14,1	23,0	2,4	5	60			

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Station: Krems-Landersdorf, 01.01.2016 - 01.10.2016

Erstellt: 26.09.2016 12:06:48 Wetterdaten bis: 26.09.2016 11:15 Vorhersage bis: 01.10.2016 11:00

Keimbereitschaft: 11.05.2016
Austrieb: 20.04.2016

Wachstum angegeben für: pro Haupttrieb (ohne Geiztriebe) Durchschnittsrebsorte

Datum	Sporulation	Sporangiendichte	Infektion	Inkubation 26.09.	Inkubation 01.10.	Temperatur °C Min.	Temperatur °C Ø	Temperatur °C Max.	Niederschlag mm	Blattnässe Std.	Blattnässe Grad-std. bei BN.	Wachstum Blattzahl	Wachstum Blattfläche cm²	Bemerkungen
18.04.						8,2	10,6	13,5	5,2	8	37			
19.04.						6,7	11,3	16,7						
20.04.						4,1	10,8	16,9				1	4	
21.04.						0,4	9,7	18,0				1	4	
22.04.						2,0	12,2	21,7				1	4	
23.04.						5,4	11,1	16,7	0,4	5	40	1	5	
24.04.						0,8	6,3	10,2	3,2	2	56	1	5	
25.04.						-1,2	4,1	10,3		1	4	1	5	
26.04.						-2,7	6,8	16,3		8	14	1	5	
27.04.						-0,3	5,2	7,8	2,0	4	20	1	5	
28.04.						-3,6	6,0	14,1		2	5	1	5	
29.04.						-2,5	7,6	16,5				1	5	
30.04.						0,5	11,2	20,0				1	5	
01.05.						2,2	11,3	17,2		1	6	1	5	
02.05.						10,1	13,4	18,4	0,2	4	21	1	6	
03.05.						8,3	12,5	19,2	1,0	5	31	1	7	
04.05.						7,8	9,1	10,5	5,2	14	59	1	7	
05.05.						7,1	11,2	18,5	2,4	9	42	1	8	
06.05.						4,1	13,9	22,3		9	80	2	13	
07.05.						5,6	15,3	23,3				2	19	
08.05.						6,2	14,4	21,4				2	23	
09.05.						4,0	15,3	22,8		3	23	2	27	
10.05.						10,0	14,9	20,6		1	6	3	39	
11.05.						10,9	15,1	20,8		2	28	3	53	
12.05.						13,2	14,0	15,2	10,8	11	62	3	63	
13.05.			!	23.05.		10,7	12,9	15,3	36,8	13	86	3	73	
14.05.						11,8	15,5	21,3	3,0	2	14	4	98	
15.05.						5,3	10,4	14,2				4	98	
16.05.						1,8	8,9	14,8	0,6	1	5	4	98	
17.05.						5,8	10,3	14,7				4	98	
18.05.						6,5	12,8	20,0				4	110	
19.05.						5,3	13,6	20,6		5	32	4	124	
20.05.						9,1	14,6	19,5	0,8	3	15	4	145	
21.05.						5,6	16,3	24,9		7	60	5	168	
22.05.						8,8	19,1	27,6				5	219	
23.05.						10,2	17,6	26,4	2,4	1	21	5	269	
24.05.			!	30.05.		9,5	12,3	17,4	7,0	9	61	6	289	

VitiMeteo
Agroscope
Staatiches Weinbauinstitut Freiburg
GEOsens Softwareentwicklung

Station: Krems-Landersdorf, 01.01.2016 - 01.10.2016

Erstellt: 26.09.2016 12:06:48 Wetterdaten bis: 26.09.2016 11:15 Vorhersage bis: 01.10.2016 11:00

Keimbereitschaft: 11.05.2016
Austrieb: 20.04.2016

Wachstum angegeben für: pro Haupttrieb (ohne Geiztriebe)

Durchschnittsrebsorte

Datum	Sporulation	Sporangiendichte	Infektion	Inkubation 26.09.	Inkubation 01.10.	Temperatur °C Min.	Temperatur °C Ø	Temperatur °C Max.	Niederschlag mm	Blattnässe Grad-std. Std.	Blattnässe Grad-std. BN.	Wachstum Blattzahl	Wachstum Blattfläche cm²	Bemerkungen
25.05.						11,4	15,5	22,1				6	344	
26.05.						7,5	16,9	25,6		12	93	6	392	
27.05.	x	86	!!	01.06.		10,2	18,1	26,0		10	140	7	449	
28.05.	x	238	!	02.06.		13,5	21,4	28,9	0,4	8	63	7	552	
29.05.						17,0	21,5	27,6				8	664	
30.05.	x	141	!	05.06.		11,7	19,1	26,1		7	86	8	745	
31.05.						11,1	18,9	24,9	0,2	2	21	9	822	
01.06.			!	07.06.		10,7	16,8	22,5		8	93	9	882	
02.06.			!	08.06.		9,8	16,8	23,4		8	96	9	953	
03.06.			!	09.06.		13,9	18,0	23,4	9,8	7	90	10	1039	
04.06.	x	76	!	09.06.		11,9	18,9	25,2		7	96	10	1118	
05.06.	x	170	!!	10.06.		14,2	18,3	24,7	7,4	12	170	10	1220	
06.06.	x	143	!	12.06.		10,6	18,1	26,0	7,0	9	97	11	1294	
07.06.						9,7	18,0	24,0		1	11	11	1361	
08.06.			!	15.06.		9,5	18,4	25,7		8	61	11	1432	
09.06.	x	186	!!!	15.06.		10,8	17,7	23,8	0,4	17	206	12	1492	
10.06.	x	232	!!!	16.06.		13,5	19,6	25,5	0,4	8	250	12	1575	
11.06.			!!	18.06.		11,3	17,1	23,3	3,2	11	115	13	1630	
12.06.	x	184	!!!	18.06.		13,6	16,6	21,5	4,2	18	358	13	1693	
13.06.	x	132	!!	18.06.		13,3	18,3	23,2	0,8	9	151	13	1760	
14.06.	x	35	!	20.06.		11,1	17,9	24,6		9	89	14	1815	
15.06.			!!	21.06.		12,6	16,4	22,7	10,6	10	107	14	1873	
16.06.						11,0	20,3	28,3		3	40	14	1945	
17.06.						11,6	18,7	22,7		2	21	15	1991	
18.06.			!	24.06.		11,8	18,4	25,9		5	57	15	2053	
19.06.			!	25.06.		10,9	18,1	25,1	0,4	8	83	15	2101	
20.06.			!!	26.06.		12,8	16,2	19,0	12,2	15	114	15	2143	
21.06.	x	110	!!	26.06.		11,2	18,9	26,5		7	110	16	2201	
22.06.	x	128	!	27.06.		13,5	20,9	27,8		6	90	16	2261	
23.06.	x	253	!	28.06.		15,0	23,5	30,1		6	99	17	2340	
24.06.						15,9	25,4	32,5			4	17	2414	
25.06.	x	300	!!	30.06.		19,2	26,3	32,3		5	111	18	2496	
26.06.						18,7	21,6	26,6		3	48	18	2562	
27.06.			!	03.07.		12,3	17,3	22,2	12,8	4	23	18	2601	
28.06.						11,8	20,0	26,8		1	17	19	2642	
29.06.						11,6	21,7	29,6		2	32	19	2695	
30.06.			!	06.07.		18,1	23,7	30,5	1,2	5	69	20	2758	

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01.07.	x	300	!!!	06.07.		14,3	22,0	29,6	4,4	10	218	20	2807	
02.07.			!	08.07.		14,2	21,5	31,3	7,0	8	33	21	2863	
03.07.	x	300				14,1	18,1	22,9	2,0	4	55	21	2894	
04.07.						13,0	19,7	26,0				21	2931	
05.07.						11,2	21,2	28,4		3	37	21	2967	
06.07.						12,1	20,1	25,5				22	3004	
07.07.						10,1	18,6	26,2				22	3031	
08.07.						9,2	20,2	28,5		2	18	22	3062	
09.07.						16,5	21,6	28,9		4	67	23	3102	
10.07.						13,2	22,9	31,2				23	3144	
11.07.	x	276				15,4	25,3	35,9		2	29	24	3194	
12.07.	x	300	!!	18.07.		17,6	22,0	31,7	42,2	13	146	24	3236	
13.07.	x	300	!!	19.07.		16,8	19,2	25,2	6,6	13	100	24	3271	
14.07.	x	276	!	20.07.		11,4	15,4	19,2	4,0	3	61	25	3285	
15.07.						10,0	16,2	22,5				25	3301	
16.07.						13,3	16,3	20,2				25	3316	
17.07.	x	103				12,8	17,9	24,8	0,8	5	49	25	3342	
18.07.						14,3	22,5	29,1		1	16	26	3375	
19.07.						12,9	22,2	29,9		2	24	26	3400	
20.07.						15,2	22,8	31,1				26	3435	
21.07.	x	202				13,0	22,4	31,6		5	42	27	3464	
22.07.	x	296				16,4	23,2	31,7		2	13	27	3490	
23.07.	x	300	!!	28.07.		18,1	24,0	31,8	1,4	7	122	27	3527	
24.07.	x	300	!!	29.07.		18,1	23,6	31,6	19,2	6	104	28	3557	
25.07.	x	300	!	30.07.		16,6	23,5	31,8		5	97	28	3578	
26.07.			!	01.08.		17,2	22,7	32,6	0,4	5	60	29	3615	
27.07.			!	02.08.		16,9	23,5	31,8		4	54	29	3635	
28.07.	x	300	!!	03.08.		16,1	21,6	30,0	3,8	8	125	29	3660	
29.07.	x	213	!!	04.08.		13,6	22,1	31,0		8	113	30	3684	
30.07.	x	197	!	05.08.		13,8	24,1	33,7		7	85	30	3700	
31.07.	x	300	!	06.08.		16,6	22,8	34,4	4,2	6	80	30	3728	
01.08.	x	300	!!	06.08.		13,1	20,5	27,1		5	170	30	3743	
02.08.	x	19				10,0	20,3	29,4		5	29	31	3754	
03.08.						16,9	22,6	32,0		1	13	31	3772	
04.08.	x	243				14,6	23,6	32,0		4	43	31	3794	
05.08.	x	258	!	13.08.		14,9	18,3	25,5	12,4	10	58	31	3802	
06.08.	x	178				13,8	19,1	28,9		2	32	32	3810	

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Datum	Sporulation	Sporangiendichte	Infektion	Inkubation 26.09.	Inkubation 01.10.	Temperatur °C Min.	Temperatur °C Ø	Temperatur °C Max.	Niederschlag mm	Blattnässe Grad-std. bei Std.	Blattnässe Grad-std. bei BN.	Wachstum Blattzahl	Wachstum Blattfläche cm²	Bemerkungen
07.08.			!	14.08.		10,1	19,9	28,7		5	60	32	3827	
08.08.			!	15.08.		10,3	21,1	31,4		6	77	32	3839	
09.08.	x	68	!!	16.08.		12,6	17,8	29,8	5,4	13	111	32	3845	
10.08.	x	231	!!	17.08.		11,3	14,6	17,9	16,0	14	162	32	3850	
11.08.						5,9	14,0	25,2		7	51	32	3852	
12.08.			!	18.08.		6,1	14,1	23,3		10	89	32	3854	
13.08.	x	122				12,5	19,4	28,3		7	63	33	3872	
14.08.	x	84	!!	20.08.		10,6	21,3	32,8		10	177	33	3882	
15.08.	x	300				13,4	20,3	29,9		3	30	33	3886	
16.08.	x	168				12,1	19,7	29,0		5	35	33	3889	
17.08.	x	158				11,0	19,0	28,5		2	17	33	3899	
18.08.	x	11	!	24.08.		7,8	18,6	30,2		8	64	33	3906	
19.08.	x	14	!!	25.08.		11,5	18,4	30,2	0,4	14	150	34	3914	
20.08.	x	143	!!	26.08.		11,6	20,4	30,3		10	186	34	3917	
21.08.	x	300	!!	28.08.		15,0	18,0	23,8	7,4	14	145	34	3919	
22.08.	x	171	!	29.08.		10,9	17,6	25,7	0,2	4	93	34	3920	
23.08.			!!	30.08.		7,9	18,5	32,5		11	110	34	3921	
24.08.	x	141	!!	31.08.		10,7	20,3	30,8		9	104	34	3928	
25.08.	x	137	!	01.09.		9,3	19,2	30,1		11	99	34	3931	
26.08.	x	16	!!	02.09.		8,6	19,8	30,9		9	140	34	3936	
27.08.	x	62				10,9	21,6	34,1		2	20	34	3937	
28.08.	x	230	!	04.09.		13,4	23,3	34,7		7	58	34	3938	
29.08.	x	300	!!!	05.09.		15,2	20,4	31,5	4,0	11	209	34	3938	
30.08.	x	255	!!	06.09.		11,5	19,8	31,5		10	120	34	3938	
31.08.			!	07.09.		7,0	17,6	28,9		8	77	34	3938	
01.09.			!	08.09.		8,5	19,9	32,0		6	56	34	3938	
02.09.			!	09.09.		10,9	19,4	32,5	5,4	12	87	34	3938	
03.09.	x	215	!!	09.09.		10,4	19,7	31,4		10	151	34	3938	
04.09.	x	159	!!	10.09.		11,9	21,1	32,1		9	135	34	3938	
05.09.	x	245	!	12.09.		14,9	17,7	23,4	7,6	8	63	34	3938	
06.09.			!	13.09.		13,2	15,0	16,3	4,0	7	50	34	3938	
07.09.	x	165				14,7	19,1	27,2		6	55	34	3938	
08.09.	x	222	!!!	14.09.		10,4	19,5	28,9		14	221	34	3938	
09.09.	x	200	!!	15.09.		11,3	21,0	32,4		9	187	34	3938	
10.09.	x	211	!!	16.09.		12,4	21,0	30,9		10	120	34	3938	
11.09.	x	213				12,3	21,6	32,8		5	52	34	3938	
12.09.	x	236	!!	18.09.		14,0	21,9	31,5		9	147	34	3938	

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Datum	Sporulation	Sporangiendichte	Infektion	Inkubation 26.09.	Inkubation 01.10.	Temperatur °C Min.	Temperatur °C Ø	Temperatur °C Max.	Niederschlag mm	Blattnässe Std.	Blattnässe Grad-std. bei BN.	Wachstum Blattzahl	Wachstum Blattfläche cm²	Bemerkungen
13.09.	x	97	!	19.09.		12,4	21,4	31,1		6	83	34	3938	
14.09.	x	102				12,8	20,1	29,1		1	10	34	3938	
15.09.	x	112	!!	22.09.		10,3	19,7	29,2		10	122	34	3938	
16.09.	x	150	!!	24.09.		12,9	20,4	30,0		10	155	34	3938	
17.09.	x	300	!!	25.09.		14,7	17,0	20,2	1,0	9	138	34	3938	
18.09.						14,4	16,8	21,2		1	5	34	3938	
19.09.						10,9	16,1	21,2		2	19	34	3938	
20.09.	x	24				9,5	13,9	20,0	1,6	4	55	34	3938	
21.09.						6,0	12,3	21,2		1	4	34	3938	
22.09.			!!	46%	30.09.	6,3	13,5	21,7		11	102	34	3938	
23.09.						3,0	12,7	23,8		10	66	34	3938	
24.09.			!	25%	95%	3,3	13,7	24,8		9	63	34	3938	
25.09.			!	12%	83%	3,9	13,7	24,3		9	67	34	3938	
26.09.						5,9	10,7	18,2		4	30	34	3938	
27.09.			!		61%	9,4	14,3	20,2		7	71	34	3938	
28.09.			!		51%	9,5	14,1	22,9		9	93	34	3938	
29.09.						14,1	18,7	23,9				34	3938	
30.09.						13,9	18,5	25,3				34	3938	
01.10.						12,1	15,0	18,5						

Sporangiendichte: Angabe in Anzahl Sporangien pro cm² Blattfläche * 1000. Werte liegen zwischen 0 und 300.

Gradstunden bei Blattnässe: werden bei durchgehender Blattbenetzung auch über Tagesgrenzen hinweg aufsummiert. Infektion wird am Tag beginnender Blattbenetzung angegeben. Wenn "Gradstunden bei Blattnässe" größer 50 ist sind Infektionsbedingungen gegeben

Inkubation aktuell: Inkubationszeit in Prozent oder Datum des Abschlusses der Inkubationszeit (wenn erreicht).
Inkubation Vorhersage: Prozent der Inkubationszeit oder Datum anhand der Wettervorhersagedaten.

Datum der Keimbereitschaft: Berechung bezogen auf Wettervorhersage

Infektion: Infektionsstärke ! gering !! mittel !!! hoch

Grau hinterlegt: Daten aus Wettervorhersage (sofern vorhanden).

Realisierung und Programmierung: Geosens Software- und Messsystementwicklung, www.geosens.com

6.7 $CaCl_2$ Extraction of Plant-Available Silicon on Soils

(modified from Haysom and Chapman, 1975 and Liang et al., 2015)

SERVES
10 samples in duplicate

20 MINUTES
16 HOURS SHAKING

2g air-dried soil

0.01M $CaCl_2$ SOLUTION

1 Liter HQ Water

1.4702g calcium chloride

As the total Si content is not related to the concentration of soluble Si in soils and can provide little information on soil Si availability to plants, this method is developed to extract plant-available Si from soils.

For the preparation of the 0.01M solution add the calcium chloride to the HQ Water.

Put 2g of air-dried soil (<2mm) into a 50-ml polyethylene tube and by pipette, add 20ml of the 0.01M $CaCl_2$ solution to the tube. Shake this for 16 hours in an overhead shaker and filtrate it with Munktell Ahlstrom paper filters with a grade of 14/N.

6.8 NaOH Extraction of Amorphous Silica in Soils

(modified from Georgiadis et al., 2015)

SERVES
25 samples in duplicate

121 HOURS

25mg of ground soil

0.2M NaOH SOLUTION

8g Sodium hydroxide
1 Liter HQ water

A solution of 0.2 M NaOH almost completely extracts amorphous silica, and when applied at room temperature and a solid: solution ratio of 1:400, only slightly brakes down crystalline Si compounds. The predictable and reproducible underestimation was considered more acceptable than the variable partial dissolution of silicates that occurs during extraction at higher temperatures. It is recommended using this method on soils from temperate-humid climate to estimate the amorphous Si fraction.

Before starting with the procedure it is important to calculate the water content of the soil. Therefore, weigh the wet and dry weight of the soil samples. Dry them at 105°C for 48 hours. The water content is calculated as a ratio of the weight of the evaporated water and the weight of the wet soil (wc = wH_20 / wwet)

Prepare the NaOH solution and grind you soil samples in a Retsch Ball Mill for 10min. In a 100ml calibrated flask, add the 0.2M sodium hydroxide solution in a ratio of 1:400 to it. Use a balance for determining the exact amount.

Afterwards shake the samples for 120 hours in an overhead shaker at room temperature and filtrate the samples with Munktell Ahlstrom paper filters with a grade of 14/N.

6.9 Adsorptiometric Determination of Silicon

(modified from Morrison and Wilson, 1963)

SERVES

10 samples in duplicate

1 HOUR 30 MINUTES

A method together with a modification for obtaining high sensitivity for determining plant-available silicon in soil. It is based on the absorptiometric measurement of solutions of reduced β-molybdosilicic acid. The limit of detection was about 0.001 ppm of silica.

Soil extraction samples (see $CaCl_2$ extraction or NaOH extraction)

HQ Water

Tartaric acid

ACIDIFIED MOLYBDATE SOLUTION

89g ammonium molybdate

62ml of 98% sulphuric acid

REDUCING AGENT

1.2g sodium sulphite

0.2g 4-amino-3-hydroxy-1-naphthalenesulphonic acid (purest grad available)

14g potassium disulphite

STANDARD SOLUTIONS OF SILICA

1000g pure dry silica

5g anhydrous sodium carbonate

All reagents should be of analytical grade unless otherwise stated. Start with the acidified molybdate solution and dissolve the ammonium molybdate in about 800 ml of water at room temperature. Dilute the sulphuric acid to about 100ml by adding it cautiously to water, with stirring, and allow to cool. Add the acid to the molybdate solution and dilute to 1 liter. The reagent may be kept for several months.

Make a 28 per cent. *w/v* solution with the tartaric acid. It can be kept for at least 3 months. For the reducing agent dissolve the sodium sulphite and 4-amino-3-hydroxy-1-naphthalenesulphonic acid in about 70ml of water. Add the potassium disulphite and shake well until dissolved and dilute to 100ml. This reagent should be freshly prepared each week.

For the standard solutions of silica fuse the pure dry silica with the anhydrous sodium carbonate in a platinum crucible at red heat. When cool, dissolve in water and dilute to exactly 1 liter. This solution contains 1000 ppm of silica. Prepare different solutions of silica by diluting. The solutions are stable for at least 3 months.

By pipette place 0.4ml of your extraction samples in 100ml calibrated flasks. Add 16ml of HQ water and 1ml of acidified molybdate solution. 10 minutes later ±3 minutes add 1ml of tartaric acid and wait for 5 minutes ±1 minute before proceeding. 0.5ml of the reducing agent is added and some samples might already become blueish. Fill up the flasks with 1.1ml to a 20ml solution. Wait one hour before measuring the optical density with a photometer.

Use the prepared standard solution to get a calibration curve of the photometer. The blank solution should contain 80ml of water of the same batch as was used for the preparing and diluting the standards. From the obtained results prepare a calibration curve.

6.10 NaOH Extraction of Amorphous Silica in Plants

(modified from Elliot and Snyder, 1991)

SERVES
24 samples in duplicate

3 HOURS

Many methodologies for the determination of Si in plant tissue are tedious and slow and/or involve cumbersome safety precautions. This new autoclave-induced digestions (AID) method has been developed to make plant tissue extraction easier. The method is linearly correlated with Si determination by NaOH fusion.

100mg ground plant tissue

HQ water

50% H_2O_2

50% NaOH SOLUTION

100mg of ground plant tissue is wetted with 2ml of 50% H_2O_2 in 100-ml polyethylene tubes. Add 4.5g of 50% NaOH solution and vortex the tubes gently.

The tubes were covered with lose fitting plastic caps and samples were placed in an autoclave at 121°C with a sterilization phase of 20 minutes. Afterwards when cooled down the content is filled up with HQ water to 50ml and samples are centrifuged at 1000 g for 5 minutes at room temperature.

Eextracts were analyzed colorimetrically with a Varian DMS 200 UV visible spectrophotometer (see 6.9 Adsorptiometric Determination of Silicon).

6.11 **LUDOX TM50 Colloidal Silica**

SIGMA-ALDRICH®

sigma-aldrich.com

3050 Spruce Street, Saint Louis, MO 63103, USA
Website: www.sigmaaldrich.com
Email USA: techserv@sial.com
Outside USA: eurtechserv@sial.com

Product Specification

Product Name:
LUDOX® TM-50 colloidal silica 50 wt. % suspension in H_2O

Product Number: **420778**

SiO_2

MDL: MFCD00011232
Formula: O2Si
Formula Weight: 60.08 g/mol

TEST	Specification
Appearance (Form)	Viscous Liquid
Appearance (Clarity) Cloudy	Conforms
pH At 25℃	8.5- 9.5
Viscosity At 25℃	≤55 cps
Specific Gravity At 60℉	1.388- 1.407
Silica	49.0- 51.0 %
Ratio SiO2:Na2O	200- 250
m2/g (Surface Area)	110- 150
Sulfates (SO4) As Na2SO4	≤0.135 %
Assay % Transmittance	≥20 %
Note Ludox TM-50	Confirmed

Remarks:
Specification Date : 11/29/2010

6.12 **Equisetum Plus**

Produktinformationen

Equisetum Plus

Art-Nr.: 20005

Pflanzenhilfs- & Pflanzenstärkungsmittel
Gemüsebau
Weinbau
Obstbau

Hoch konzentrierter Schachtelhalmextrakt (Equisetum arvense)

Equisetum Plus ist ein Schachtelhalmextrakt (*Equisetum arvense*) in welchem als Hauptbestandteile pflanzliche Kieselsaure und Schwefelverbindungen enthalten sind.

Wirkungsweise:
Aufgrund seines hohen Siliziumgehaltes fördert Equisetum Plus die bessere Ernährung und Kräftigung der Pflanze. Natürliche Kieselsäure wird verstärkt in die Zellwände eingelagert (Verkieselung). Dies festigt Zellwände und Epidermis und stärkt somit die Pflanzen gegenüber abiotischem Stress. Entscheidend für den Behandlungserfolg ist eine regelmäßige Anwendung während der gesamten Vegetation.

Anwendung:
Kernobst: 1 %ig ab Mitte August; 3–4 Anwendungen (3–4 l pro ha)
Reben: 1 %ig; 2 Anwendungen vor der Blüte, nach der Blüte 3–4 Anwendungen
Gemüse: 1 %ig in regelmäßigem Abstand

Anwendungshinweise:
Equisetum Plus ist sowohl zum Gießen als auch zum Spritzen mit den üblichen Spritz- und Sprühverfahren geeignet.
Zur Bodenbehandlung die Erde gut überbrausen.
Zur Pflanzenbehandlung die Pflanzen von allen Seiten benetzen.
Es empfiehlt sich bei Sonnenschein zu spritzen; ein schnelles Antrocknen unterstützt die pflanzenstärkende Wirkung.
Unverträglichkeiten sind nicht bekannt.

Weitere Informationen

Sicherheitsdatenblatt: Equisetum plus SDB_D.pdf
Sicherheitsdatenblatt CLP: SDB Insecto_Sec_AT 201505192.pdf
Zusatz: Schachtelhalmextrakt
Gebindegrößen: 10 und 25 Liter
infoxgen: 1

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1.1 **Silicon in Soil**

In rocks, the concentrations of silicon range from 23% (e.g. basalt) to 46.5% (e.g. orthoquartzite). Trance amounts of silicon are also in carbonaceous rocks (Monger and Kelly, 2002). The chemical weathering of silicate-containing minerals is the ultimate source of dissolved Si (as monosilicic acid, H_4SiO_4), which contributes to continental soil formation through linked biogeochemical reactions. Silicon release to the soil solution from weathering of silicate-containing minerals is rather slow and is governed by precipitation and neoformation of authigenic Si-constituents, Si adsorption/desorption on various solid phases, uptake and assimilation by vegetation and microorganisms, preservation of stable Si form in the profile, and addition from external atmospheric inputs. The largest inter-pool Si transfer takes place between biomass, biogenic silica from phytoliths and microorganism and soil solution (Tubana et al., 2016). The contribution of silicon to the soil solution from the atmosphere via wind-blown dust and phytolith particles is very small compared to soil-plant inputs (Tubana et al, 2015).

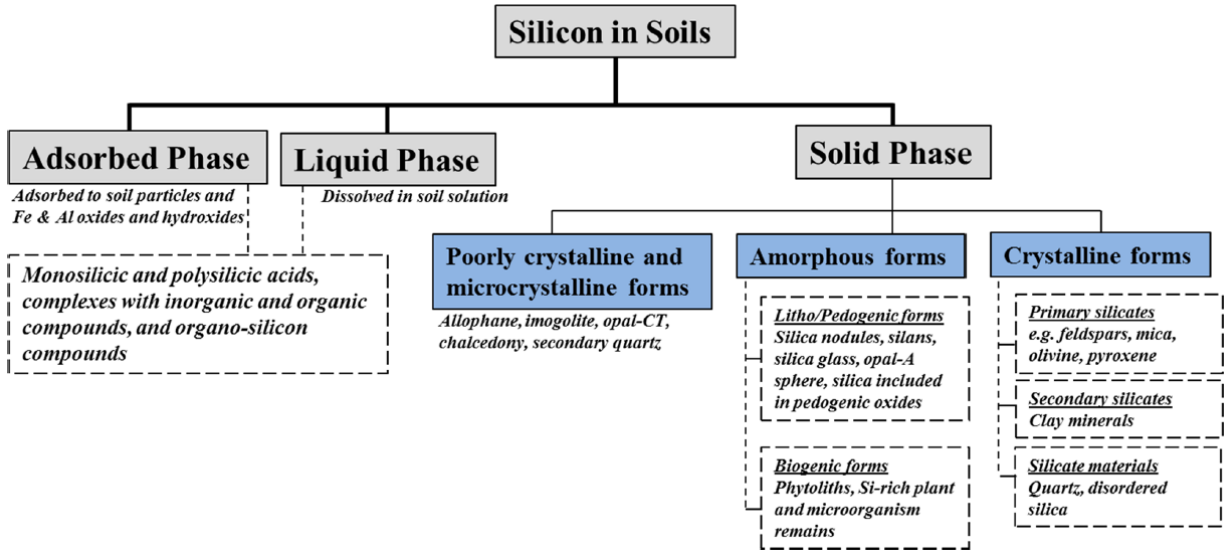

Figure 1: Different fractions of Si in soils (Tubana et al., 2016)

In soils, silicon is generally grouped into three different fractions (1) the liquid phase, (2) the adsorbed phase and (3) the solid phase, which are the key components of the silicon cycle in soil (Matichencov and Bocharnikova, 2001). Figure 1 shows the different fractions in the classification of silicon compounds in soils. The solid Si phase consists of poorly crystalline and microcrystalline, amorphous and crystalline forms of Si. The largest solid phase fraction of Si occurs in crystalline form consisting of primary and secondary silicates. Amorphous Si originates either from biogenic sources such as plant residues and remains of microorganisms or litho/pedogenic materials, which are Si complexes with Al, Fe, heavy metals and soil organic matter. The amount of amorphous Si ranges from less than 1,000 to 30,000 mg/kg on a total soil basis and effects the concentration of Si in soil solution (Tubana et al., 2016). The components of silicon in liquid and adsorbed phases are similar, with exception that those in liquid phase are dissolved in the soil

1.1.1 Soluble and Available Silicon in Soils

Primary silicates and secondary mineral phases containing silica and biogenic silica to some extent dissolve in water to produce silicic acid. It is produced by a non-biological process called hydration involving water and quartz (Cooke et al., 2011). The reaction producing silicic acid from quartz can be written as:

$$\text{Quartz} + \text{Water} \rightarrow \text{Silicic acid}$$
$$SiO_2 + 2\ H_2O \rightarrow H_4SiO_4$$

Silicic acid concentration varies with soil type and is affected by its dissolution from soil minerals and its adsorption or resorption by the soil (Epstein, 1994). Extreme conditions including high temperatures and rainfall increase the release of silicic acid, explaining why most weathered soils in the tropics are silicon-deficient (Cooke at al., 2011).

Silicic acid (H_4SiO_4) is the only form of Si present in soil solution, whereas the measured concentrations range between 0.1 – 0.6 mM (Epstein, 1994), which is much less than that in saturated silicic acid solution and is mainly controlled by the pH-dependent absorption-desorption processes on sesquioxides (Liang et al., 2015). Available Si in soils refers to an amount of Si that can be taken up by plants during the growing season and is considered an index of Si-supplying capacity in soil. However, in silicic acid-saturated soil solution the monosilicic acid polymerizes into polymeric acid, which is in a dynamic equilibrium with amorphous and crystalline silicates, exchangeable silicates and sesquioxides. Therefore, parts of silicate components that can be easily converted into silicic acids such as polymerized silicic acid, exchangeable silicates and part of colloidal silicates also count to available Si (Liang et al., 2015).

The main factors influencing soil Si availability or Si-supplying power include types of soil and parent material, historical land-use change, soil pH, soil texture, soil redox potential, organic matter, temperature and accompanying ions (Liang et al., 2015). Moreover, the results of Biyutskii et al. (2016) highlight the importance of earthworms in plant acquisition and biogeochemistry of Si. Earthworms can increase mobility and bioavailability of silicon in soils.

1.2 Silicon in Plants

As other plants grapevines require three categories of resources to grow and produce fruit: (1) carbon, (2) water and (3) mineral nutrients. Exposed to suboptimal conditions abiotic and biotic stresses can be limiting to one or several resources to the plant. Abiotic stresses include overcast or too bright sky, heat or cold, water surplus or deficit and nutrient deficiency. Pests and disease attacks rank among biotic stresses. Grapevines share their living quarters with a wide range of other organisms, mainly arthropods and microorganisms, and in addition to some nematodes, birds, mammals and plants. Although the majority of these do not harm grapes, some organisms compete with the vines for resources or make a living feeding on various grapevine structures, which make them pests or pathogens (Keller, 2010). Although a certain level of stress will improve fruit quality in the vineyard, stresses adversely affect plant growth, development, or productivity. (Bauer et al., 2015).

Although not traditionally thought of as an element essential to the life cycle of plants, with the exception of the early-diverging *Equisetaceae*, Si is found in plants at concentrations from 1 to 100 g/kg which is equivalent to or even exceeding several macronutrients (Epstein, 1994). For plant nutrition silicon has not been considered as an essential element, according to the classical definition of essentiality (Arno and Stout, 1939), but it is regarded as one of the most beneficial elements that increases plant resistance against abiotic and biotic stresses. It has been shown to improve plant cell wall strength and structural integrity, improve drought and frost resistance, decrease lodging potential (Currie and Perry, 2007), and boost the plant's natural pest and disease fighting systems (Datnoff, 2007). Silicon has also been shown to improve plant vigor and physiology by improving root mass and density, and increasing above ground plant biomass and crop yields (Epstein, 2009b). In 2013, the American Association for Plant Food Control Officials (AAPFCO), the regulatory body that governs the labeling of fertilizers in the USA, recognized silicon as a beneficial substance that can now be sold as a fertilizer across the USA (Datnoff et al., 2015).

Silicic acid is the only known precursor of silicon compounds in biota, and plants take up aqueous, uncharged silicic acid through their roots when the pH-value of the soil solution is below 9 (Ma and Yamaji, 2006). The ability of plants to accumulate Si varies greatly between species. Silicon accumulation has been found to a greater extent, but not exclusively, in monocotyledonous plants. Plants of the families *Poaceae*, *Equisaetaceae* and *Cyperaceae* show high Si-accumulation whereas different parts of the same plant can show large differences in Si-content. Silicon concentration of shoots typically tend to decline in the order

liverworts > horsetail > clubmosses > mosses > angiosperms > gymnosperms > ferns

(Currie & Perry, 2007). Its uptake is passive for dicotyledons and largely determined by transpiration rate and is transported in the xylem. Therefore, silicon accumulates in higher amounts in mature leaves than in young ones (Ma and Takahashi, 2002). The absorption of silicic acid takes place at the lateral roots also via active or rejective mechanisms (Tubana et al. 2015).

1.3 **Major Fungal Pathogens of Grapevine**

Grapevine species are prone to several diseases, fungi being the major pathogens compromising its cultivation and economic profit around the world. Knowledge of the complexity of mechanisms responsible for resistance to fungus infection is necessary to develop strategies which will improve the grapevine's resistance (Bauer et al., 2015).

1.3.1 Powdery Mildew

Uncinula necator (syn. *Erysiphe necator*) is a fungus that causes grapevine powdery mildew, also termed Oidium. It is the most widespread and most consistently damaging pathogen which is parasitic on genera within the *Vitaceae*. The most economically important host is grapevine (*Vitis*), particularly the European grape, *Vitis vinifera*, which is highly susceptible. The fungus originated in North America and spread through Europe in the 1840s at a time where little was known about germ theory (Gadoury et al., 2012).

Uncinula necator infects all green tissue on the grapevine, including leaves and young berries. Ascospores colonies are most commonly found on the lower surface of the leaves and may be accompanied by a similarly shaped chlorotic spot on the upper surface. Severely affected leaves usually senesce, develop necrotic blotches and fall prematurely. Inflorescences and berries are most susceptible when young and can become completely coated with whitish mildew. Powdery mildew causes crop loss and poor wine quality if untreated (Bauer et al., 2015).

This fungus requires only 40% relative humidity to germinate, a threshold that is easily reached on the lower surface of transpiring leaves, even if the surrounding air is much drier. The optimum is at 85% humidity and 25°C, but heavy rain and temperatures below 10 and over 31°C limit the development. Mild rainfall seems to benefit by enhancing spore dispersal. Spores germinate on the surface of plant organs, invade the cuticle and cell walls and rapidly establish haustoria inside the epidermis cell. Like all biotrophic pathogens, *U. necator* needs living host plants for assimilate supply. It suppresses the defense responses in susceptible cultivars and acts as another sink. Infected leaves have higher concentration of sugars especially hexoses due to import of sucrose from uninfected plant parts and subsequent breakdown by invertase in the cell walls. An injection of cytokinin from the pathogen induces invertase activity and also involves amino acid imports. Photosynthesis and starch storage will decrease in infected leaves. This powerful extra sink alters assimilates partitioning in the vine at the expense of other sinks such as fruit, roots and storage reserves (Keller, 2010).

Unlike American *Vitis* species, which are relatively resistant to the fungus, European *Vitis vinifera* L. cultivars are readily infected because they did not coevolve with the pathogen and produce lower amounts of PR proteins. Within European cultivars susceptibility varies, with Chardonnay and Cabernet Sauvignon being among the most susceptible cultivars (Keller, 2010). Even though

stilbene phytoalexins are also effective against *Uncinula necator,* infections do not normally trigger their production. One explanation could be that the fungus avoids cell damage so as not to threaten its own survival. The resistant American *Vitis* species accumulate stilbenes in response to infections. Also flavonols, which accumulate in the epidermis, and cuticular wax may be involved in Vitis *vinifera* resistance against *Uncinula necator* (Keller, 2010). Flavonol production is strongly reduced by high soil nitrogen availability and high plant N status makes vines more susceptible to colonization by powdery mildew. An additional resistance mechanism may be vitrification of penetrating mycelium by the localized accumulation of silicates in the cell walls (Blaich and Wind, 1989).

Figure 2: Symptoms of powdery mildew, left: fully infested grape cluster (own picture), right: spots of powdery mildew on the adaxial side of the leaf (www.rebschutzdienst.at)

1.3.2 Downy Mildew

Although usually regarded as a fungus because it looks like one and produces spores, the causal agent *Plasmopora viticola* is in fact more closely related to certain algae, kelps and diatoms with which they are placed in the kingdom of Protista. In contrast to fungi, its cell walls contain cellulose instead of chitin and its cell nuclei are diploid, not haploid. It belongs to the class of Oomycetes and is not related to the powdery mildew fungus. (Gessler et al., 2011)

Plasmopora viticola also termed Peronospora can infest all green parts of the plant but usually colonizes young leaves or young berries by penetrating through the stomata. The spores can germinate at greater than 95% relative humidity in shady conditions especially with frequent rainfall and temperatures between 20 and 25°C. The mycelium develops an intercellular network in the leaf mesophyll and creates haustoria to feed from these cells. The first symptoms appear on the adaxial side of leaves as yellow or in some cultivars red oily spots, which spread and later

1.4 **Defense and Resistance of Grapevine**

A prospective pathogen that attempts to penetrate the epidermis first has to overcome the cuticle and thick outer cell walls on the leaves. The thickness of the cuticle and the outer cell wall of different *Vitis* cultivars determine their susceptibility to powdery mildew (Heintz and Blaich, 1989). Access points for pathogens are wounds caused by herbivore, birds, arthropods or mechanical damage. During anthesis exposed surfaces provide ideal sites for pathogen invasion and therefore special attention for plant protection has to be paid during flowering. Plants respond to physical damage by mechanisms that aim to heal wounds and prevent pathogen invasion. Deposition of callose, lignin glycoproteins and phenolics strengthen the cell wall and the production of so-called pathogenesis-related (PR) proteins such as chitinases and glucanases increase the defense mechanism (Gessler et al., 2011).

If defense responses are unsuccessful and pathogens penetrate into the tissues, plants have evolved a broad range of strategies to resists fungal infections. These strategies are either constitutive or induced. Constitutive resistance strategies are passive and are present regardless of an infection. They include physical barriers such as cell walls, the cuticle and chemicals with antimicrobial activity like phenolics, which are generally accumulated in the cell vacuoles (Keller, 2010).

Induced strategies are actively initiated in response to pathogen invasion and specifically target pathogens that have overcome the constitutive barriers. The production of reactive oxygen species and antimicrobial compounds such as proteins and phytoalexins starts. The fortification of cell walls with lignin, suberin or the incorporation of callose, proteins or silicon are part of the induced strategies. Active defense is usually restricted to the site of invasion as only infected and neighboring cells accumulate the antimicrobial chemicals to concentrations to restrict the spreading of the pathogen (Keller, 2010; Gessler et al., 2011). The first hypothesis of silicon-enhanced resistance is associated with silicon deposits in the cell walls and below the cuticle which act as an addition physical border (Sakr, 2016).

Plants have special receptor proteins that can recognize invading pathogens by some of the microbial enzymes or complex carbohydrates. They are able to interpret the breakdown products of their own cuticle and cell walls as signals of the intruder. These compounds are collectively termed elicitors. The defense response results from activation of various biochemical pathways by a series of signaling cascades that are triggered by the detection of a pathogen. Within minutes of an attempted infection by a foreign invader, there is a rapid rise in reactive oxygen species in the apoplast (Apel and Hirt, 2004). The surrounding cells mount structural barriers and produce PR-proteins which degrade chitin and glucans, which are important components of the cell walls of fungi (Keller, 2010).

Secondary signaling molecules, including salicylic acid, jasmonic acid and ethylene then augment the early defense response and may even activate defenses in distant healthy tissues and act systemically (Heil and Ton, 2008). In some instances, these secondary signals and H_20_2 make

infected and surrounding cells to commit suicide in a process termed hypersensitive response. This limits food supply to the pathogen and may kill it. Although, this strategy is indeed useful in fighting off biotrophs such as *Unicator. neca*tor and *Plasmopora. viticola*, the susceptibility to necrotrophs rises. Necrotrophs such as *Botrytis cinerea* grow on dead tissues and can exploit the plant's defense response by promoting tissue senescence. (Keller, 2010)

If the pathogen could penetrate into the tissue, the vine activates a second line of defense after several hours. This biochemical defense includes accumulation of antimicrobial compounds, including phytoalexins and PR proteins. In response to xylem-invading fungal pathogens, the accumulation of elemental sulfur in the vessel walls and xylem parenchyma cells is expedited (Gessler et al., 2011).

1.5 **Research Objective**

The aim of this thesis is to test the efficiency of silicon applications to control for downy and powdery mildew in grapevine *V. vinifera* L. cv. Grüner Veltliner in a field trial. In the literature two hypotheses for silicon-enhanced resistance to fungal diseases have been proposed: (1) Increased levels of silicon deposits in the plant act as physical barriers and (2) the upregulation of natural defense mechanism which actively fight off fungal pathogens.

Previous studies have shown that the supplement of silicon to grapevine increased the maximum yield and potential photochemical efficiency of the photochemical reactions in photosystem II (Qin et al., 2016). Ling et al. (2016) state that silicon might play an important role in protecting photosynthetic machinery from damage and improving the salt-tolerance of the grapevine by increasing the concentration of soluble sugars and starch.

On potted plants root-feeding at 1.7mM silicon solution had no effect on fungal disease severity, but foliar sprays at 17mM Si substantially reduced the number of mildew colonies that developed in inoculated grapevine leaves. Hyphae did not develop in areas where thick Si deposits were present on the leaf surface (Bowen et al, 1992). Reynolds et al. (1995) showed that potassium silicate sprays reduced the incidence of powdery mildew in two of three years. The study concluded that grape berries may utilize endogenous Si to help fight diseases. Furthermore, exogenously applied silicates may act to augment the activity of their endogenous counterparts. Appropriate application intervals and concentrations will increase the effectiveness of silicon sprays.

Klaus et al. (1990) performed a Si-fertilizer trial in a vineyard with grapevine cv. Müller-Thurgau and Silvaner. Vines were fertilized with 2.5 and 5 t/ha of calcium silicate over four years before starting measurements. Minor Si accumulation in the tested leaves could be determined. However, Leusch (1986) indicates that the fertilization with calcium silicate does not always lead to an increased amount of silicic acid due to a rise in pH and therefore a reduced solubility. The

2 Material & Methods

2.1 Experimental Design

The field trial was situated in Krems Landersdorf at a vineyard of the School of Viticulture and Horticulture in Krems, Austria and was supported by Ing. Christoph Gabler and Ing. Erhard Kührer. For each treatment 48 plants of *Vitis vinifera* cv. Grüner Veltliner (scion: SO4) were used and divided into four groups of 12 plants. The vineyard was planted in 2012 with a distance of 3x1m (Figure 4).

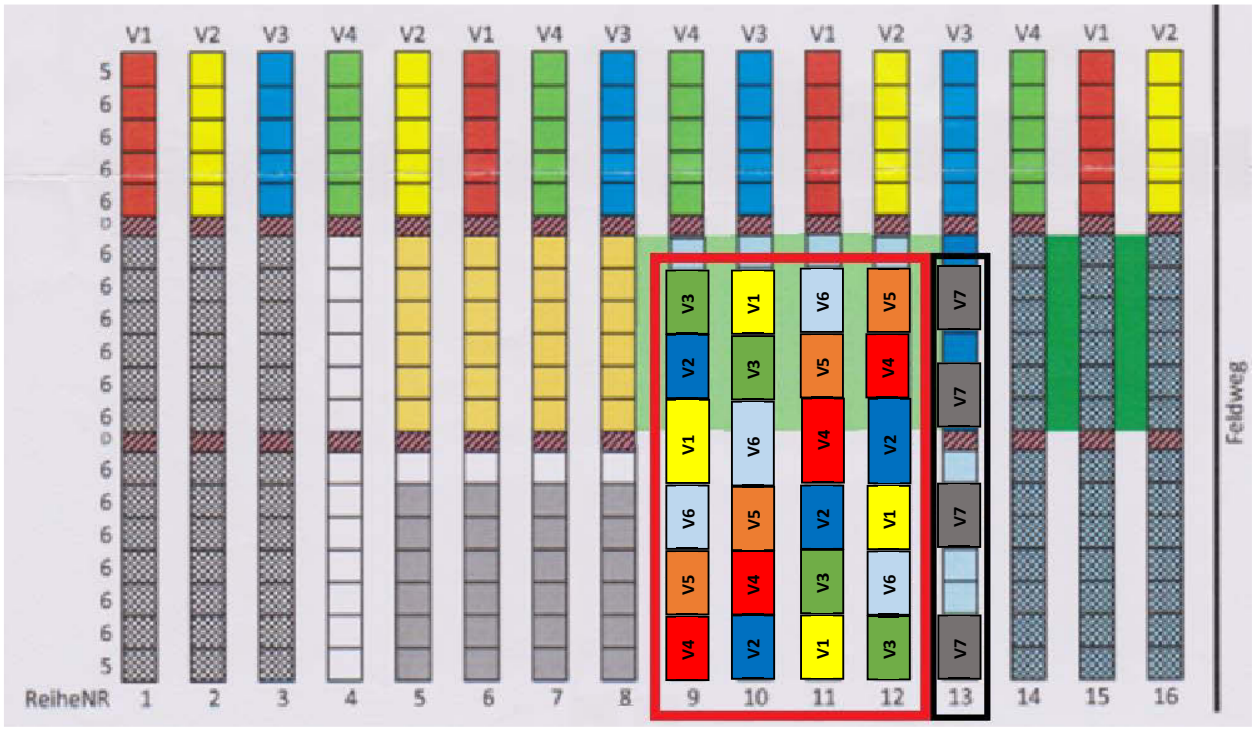

Figure 4: Experimental design, V1: Amorphous Silicon Soil Amendment (yellow), V2: Amorphous Silicon Foliar Spray (blue), V3: Amorphous Silicon Combination V1 + V2 (green), V4: Equisetum Plus Spray (red), V6: Control Group Water Spray (light blue), V7: Control Group Common Plant Protection (grey), colored blocks consisted of 12 plants, total number of plants per treatment were 48

Amorphous silica was either applied to the soil as a fertilizer (V1) or sprayed as foliar spray to the canopy (V2). For treatment V3 a combination of Si-fertilization and foliar spray was used. In treatment V4 a horsetail extract, which has already been used in organic viticulture was applied as foliar spray. The control groups V5 and V6 received water sprayed on leaves and soil irrigation with water, respectively. Treatment V7 served as a comparison to common plant protection.

2.2 **Soil Characteristics**

Before starting the experiment soils of different vineyards were analyzed to ensure low plant-available and amorphous silicon in the soil. The vineyard at Krems, Landersdorf is low in both silicon fractions. Table 1 shows the analysis of silicon in the soils of the experimental vineyard. Plant-available (i.e. $CaCl_2$-extractable) Si amounted to 0.126 mM in the topsoil and 0.118 mM in the subsoil which compares to a typical range between 0.029 – 0.175 mM plant-available silicon (Sakr, 2016), indicating a medium available Si status of the experimental soil. Similarly, also for the amorphous fraction (i.e., NaOH-extractable) of silica (1.25 g/kg in the top and 1.37 g/kg in the subsoil) falls in the lower range compared to the typical range of 1,000 to 30,000 mg/kg as reported by Tubana et al. (2016).

Table 1: Silicon analysis of the vineyard in Krems, Landersdorf, soil samples were taken on March 18, topsoil ranges from 0-30 cm, subsoil ranges 30-60 cm, plant-available silicon was analyzed with a $CaCl_2$-extraction modified from Haysom and Chapman, 1975 and Liang et al., 2015, amorphous silicon was extracted with a NaOH-solution modified from Georgiadis et al., 2015

Soil Analysis	Plant-available Silicon (in mM)	Amorphous Silicon (in mg/kg)
Topsoil	0.126	1,250
Subsoil	0.118	1,370

Table 2 provides additional information about the soil characteristics of the vineyard. According to its texture composition of around 100 g/kg sand, 700 g/kg silt and 200 g/kg clay it can be classified as loess soil, an aeolian sediment formed by the accumulation of wind-blown silt (Miller et al., 1990). A thick blackish mineral surface layer that is rich in organic matter and the parent material of mostly aeolian and reworked aeolian sediments indicate the classification of a Chernozems soil. This soil is typical for this region and develops in a continental climate (FAO, 2015). The carbon-to-nitrogen ratio at a medium level for a cultivated Chernozem soil.

Table 2: Characteristics of the experimental soil in Krems, Landersdorf, analysis was performed according to Blum et al. (1996)

Soil	pH	Sand	Silt	Clay	C/N ratio	Organic Carbon	Carbonate Content	Nitrogen
Topsoil	7.43	100 g/kg	672 g/kg	228 g/kg	13.8	19.3 g/kg	184.9 g/kg	1.4 g/kg
Subsoil	7.55	89 g/kg	758 g/kg	153 g/kg	16.4	16.4 g/kg	192.1 g/kg	1.0 g/kg

2.3 Treatments

[V1] **Amorphous Silicon – Soil Amendment**
LUDOX TM-50 Colloidal Silica was applied to the soil with a watering pot in 6 portions during the growing season. For an easier application and to avoid drain of the fertilizer a pouring ring around the vine with a diameter of 40cm were installed. A total amount of 5 t/ha LUDOX TM-50 Colloidal Silica were applied (Table 3). Taking into account that this is a 50% wt. suspension in water, this corresponds to a total amount of 2.5 t/ha of silica.

Amount of application for 48 plants:

Table 3: Detailed information for the soil amendment with LUDOX TM-50 Colloidal Silica for the treatment V1 and V3. The same amount of water was used for the control group V5, the BBCH-code identifies the phenological stages of the grapevine

Date	BBCH	Product	Amount	Concentration	Water	M SiO_2 per Plant
19-May	17	LUDOX TM-50 Colloidal Silica	8.0 l	4.20%	192 l	93.0
7-Jun	57	LUDOX TM-50 Colloidal Silica	3.2 l	1.70%	192 l	37.2
28-Jun	73	LUDOX TM-50 Colloidal Silica	3.2 l	1.70%	192 l	37.2
12-Jul	77	LUDOX TM-50 Colloidal Silica	3.2 l	1.70%	192 l	37.2
29-Jul	81	LUDOX TM-50 Colloidal Silica	3.2 l	1.70%	192 l	37.2
17-Aug	83	LUDOX TM-50 Colloidal Silica	3.2 l	1.70%	192 l	37.2

[V2] **Amorphous Silicon – Foliar Spray**
The first two applications were sprayed at a concentration of 1% of LUDOX TM-50 colloidal silica. After the first assessment of fungal diseases the amount was increased to a concentration of 2% to gain better results (Table 4).

Amount of application for 48 plants:

Table 4: Detailed information of the foliar spray with LUDOX TM-50 Colloidal Silica for the treatment V2 and V3. The same amount of water was used for the control group V6, the BBCH-code identifies the phenological stages of the grapevine

Date	BBCH	Product	Amount	Concentration	Water	mM SiO_2 per Plant
19-May	17	LUDOX TM-50 Colloidal Silica	50ml	1.00%	5 l	12.1
7-Jun	57	LUDOX TM-50 Colloidal Silica	60ml	1.00%	6 l	14.5
28-Jun	73	LUDOX TM-50 Colloidal Silica	160ml	2.00%	8 l	38.8
12-Jul	77	LUDOX TM-50 Colloidal Silica	160ml	2.00%	8 l	38.8
29-Jul	81	LUDOX TM-50 Colloidal Silica	160ml	2.00%	8 l	38.8
17-Aug	83	LUDOX TM-50 Colloidal Silica	200ml	2.00%	10 l	48.5

2.4 Plant Protection

Additionally, conventional spraying as foliar spray was applied to all treatments and controls except for the common plant protection (V7) (Table 6). This basic plant protection was used depending on weather conditions and infection risk of fungal pathogens. It was planned to implement silicon applications into an organic viticulture plant protection plan, which uses mainly copper and sulfur. Due to high infection risk of *Plasmopora viticola,* Aktuan Gold, a systemic fungicide, was used once to keep downy mildew at bay.

Amount of basic plant protection applications for 48 plants:

Table 7: Detailed information of the basic plant protection for all treatments.

Date	BBCH	Product	Amount	Concentration	Water
16-Jun	68	Cuprozin Progress (Copper)	26ml	0.40%	6.5 l
		Stulln (Sulfur)	45.5g	0.70%	
24-Jun	73	Aktuan Gold	40ml	0.40%	10 l
1-Aug	81	Cuprozin Progress (Copper)	50ml	0.40%	12 l
		Stulln (Sulfur)	85g	0.70%	
15-Aug	85	Cuprozin Progress (Copper)	50ml	0.40%	12 l
		Stulln (Sulfur)	85g	0.70%	

2.5 Time Table

Figure 5 gives an overview of all actions during the field experiment. Silicon applications of soil amendment and foliar spray started in week 20 in the mid of May and ended at week 33 in the mid of August. Soil samples were taken right before soil amendment, after three applications of silicon and after 6 applications. Leaf samples were taken after each two applications of silicon. The analysis of photosynthesis was measured 5 times over the vegetation period. Fruit quality was measured at harvest time.

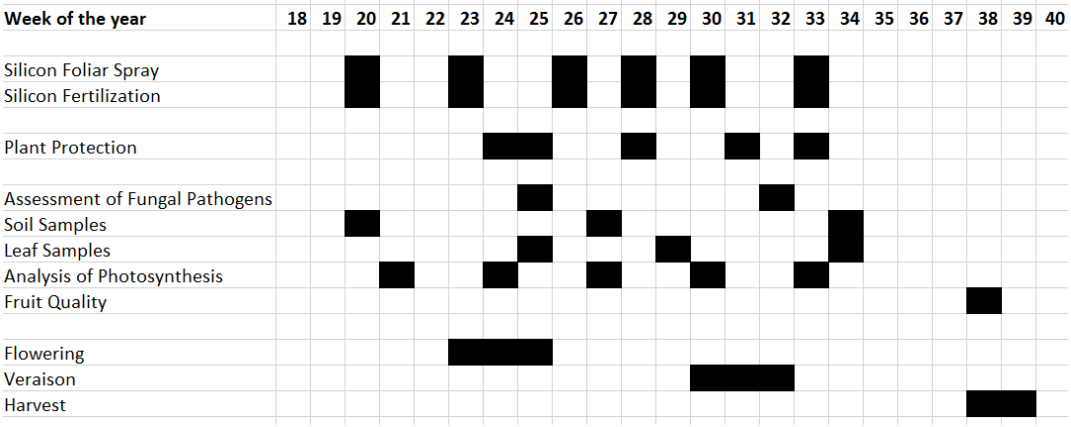

Figure 5: Time table of all applications and measurements

2.6 Weather Data

The vegetation period in 2016 was dominated by frequent rainfalls. June and July had three times higher precipitation than in the year before (Tables 7 and 8). Average relative humidity was in these months also higher in 2016 compared to 2015. These are two important factors which favor spreading and infections of fungal pathogens and presented viticulturists with a challenge for plant protection.

A detailed overview from Vitimeteo, a forecast system for plant protection in viticulture, of daily rainfalls and fungal infections can be found in the Appendix.

Table 8: Weather data 2015 from Adcon Telmetry Live Data, Krems Landersdorf

Weather Data 2015	April	May	June	July	August	September
Average Temperature (°C)	10.8	14.9	19.4	23.5	23.0	15.3
Minimum Temperature (°C)	-2.7	5.6	10.6	9.0	9.3	3.6
Maximum Temperature (°C)	25.9	33.7	38.5	38.0	38.0	35.5
Precipitation (mm)	8.8	64.2	23.8	32.2	61.6	76.0
Average Relative Humidity (%)	60	73	67	59	64	67
Minimum Relative Humidity (%)	20	26	22	20	17	25
Maximum Relative Humidity (%)	97	100	99	100	100	100

Table 9: Weather data 2016 from Adcon Telmetry Live Data, Krems Landersdorf

Weather Data 2015	April	May	June	July	August	September
Average Temperature (°C)	10.4	14.9	19.3	21.3	19.4	17.5
Minimum Temperature (°C)	-2.3	4.0	10.3	11.1	7.3	4.3
Maximum Temperature (°C)	23.6	27.4	32.8	35.1	31.6	30.9
Precipitation (mm)	39.4	70.8	70.4	96.0	45.8	19.6
Average Relative Humidity (%)	69	71	73	71	73	74
Minimum Relative Humidity (%)	24	35	36	29	25	34
Maximum Relative Humidity (%)	100	100	98	100	100	100

2.7 **Measurements**

2.7.1 Assessment of Fungal Diseases

Infections of Powdery Mildew (Uncinula necator) and Downy Mildew (Plasmopara viticola) were documented at two times during the period according to EPPO standards PP 1/31(3) *Plasmopara viticola* and PP 1/4(4) *Uncinula necator*, which can be found in the Appendix. The first time was on June 24 where only Downy Mildew was assessed due to a lack of symptoms from Powdery Mildew. The second assessment was on August 11 where both fungal diseases were monitored. Figure 8 shows the percentage of infected leaf surface as a guideline for assessing fungal infections.

To assess percentage of leaf surface and affected bunch area, the following scale was used to class-divide the different levels of infection:

1 = no disease
2 = <5%
3 = 5-10%
4 = 10-25%
5 = 25-50%
6 = 50-75%
7 = >75%.

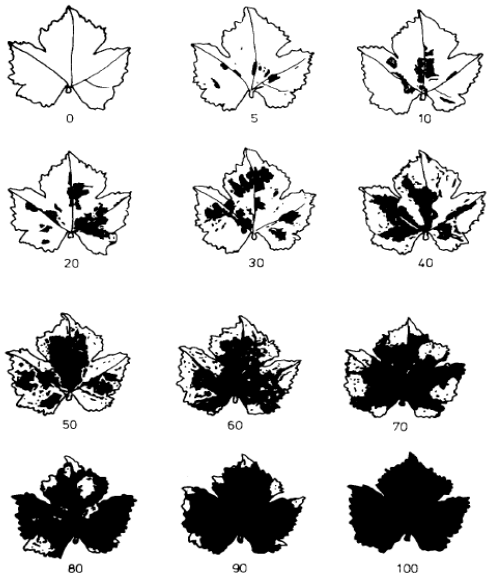

Figure 6: Overview of the percentage of abaxial leaf surface affected by downy mildew (EPPO standards PP 1/31(3))

Out of these classes two performance indicators were calculated:

n ..... number of observation
i ..... number of class
$n_{(c_i)}$ ..... number of observation in class i

Rate of Infestation: $$\frac{\sum_{i=2}^{7}\left(n_{(c_i)}\right)}{\frac{n}{100}}$$

Intensity of Infestation: $$\frac{\sum_{i=2}^{7}\left(n_{(c_i)} * (i-1)\right)}{6 * \sum_{i=1}^{7}\left(n_{(c_i)}\right)}$$

2.7.2 Soil Analysis

Plant-available and amorphous silicon fractions were analyzed in soil samples collected from the top (0-30cm) and subsoil (30-60cm) during the vegetation period at three points of time. The points of time were before the silicon soil amendment, after three silicon applications and after six silicon applications.

The soil amendment treatments were [V1] Soil Amendment, [V3] Soil Amendment + Foliar Spray and [V5] Control – watered. Each treatment is divided into 4 fields with 12 plants. From each field 6 soil samples from the top and subsoil were taken and mixed. Samples were taken three times during the vegetation period. Thus from each treatment 72 (4 fields * 6 samples *3 times) soil samples from the topsoil and 72 samples of the subsoil were taken. Resulting in total of 12 batches of mixed soil samples from the topsoil and 12 batches of mixed soil samples from the subsoil from each treatment.

The level of plant-available silicon in soil was analyzed with a $CaCl_2$-extraction method using a 0.01M solution modified from Haysom and Chapman, 1975 and Liang et al., 2015. 2g of air-dried soil (<2mm) were mixed with 20ml of the 0.01M $CaCl_2$ solution in a tube and were shaken for 16 hours in an overhead shaker and filtrated it with Munktell Ahlstrom paper filters with a grade of 14/N. The amorphous silicon was extracted with a NaOH-extraction method modified from Georgiadis et al. (2015). A 0.2M sodium hydroxide solution was used in a ratio of 1:400 and samples were shaken 120 hours in an overhead shaker. Samples were analyzed in one replicate.

Filtered extracts of both extractions were analyzed colorimetrically with a Varian DMS 200 UV visible spectrophotometer. This analysis is based on the absorptiometric measurement of solutions of reduced β-molybdosilicic acid (modified from Morrison and Wilson, 1963).

Detailed descriptions of the used methods can be found in the Appendix.

2.7.3 Leaf Analysis

To gain knowledge about the amount of silicon allocated to leaves, samples from mature and young leaves were taken at three time points. Mature leaves were taken from the fruit zone and differ in their leaf age from one to another sample time. Young leaves were side shoots of the same developmental stage. The points of time were after 2, 4 and 6 applications of silicon. From each treatment 20 old leaves and 40 young leaves were taken at every sampling time.

Leaves were dried at 65°C for 48 hours in an oven. They were ground with a Retsch ball mill to pass a 20-mesh screen. The amorphous silicon content was extracted by an autoclave-induced extraction method (modified from Elliot and Snyder, 1991). A 50% H_2O_2 -Solution and a 50% NaOH-Solution was added to the plant material and samples were placed in an autoclave at 121°C with a sterilization phase of 20 minutes. Samples were analyzed in one replicate.

Centrifuged (1000 g, 5min, room temperature) extracts were analyzed colorimetrically with a Varian DMS 200 UV visible spectrophotometer (modified from Morrison and Wilson, 1963).

Detailed descriptions of the used methods can be found in the Appendix.

2.7.4 Analysis of Photosynthesis

Hansatech Handy PEA chlorophyll fluorimeter was used for measurement of chlorophyll fluorescence five times during the vegetation period. Any forms of biotic or abiotic stress which have an effect on the photosynthetic performance, will change the intensity of the chlorophyll fluorescence emission. Healthy samples typically achieve a maximum value of Fv/Fm of 0.85. Plants with lower values are exposed to stress, which reduced the capacity for photochemical quenching of energy within photosystem II (Hansatech Handy PEA Manual).

When light energy from the sun is absorbed by a chlorophyll molecule within a sample, the electronic configuration of the molecule is temporarily altered. Photochemical and non-photochemical processes compete to dissipate the absorbed energy. Photochemical processes utilize absorbed energy for the photosynthesis, whereas non-photochemical processes dissipate energy, which is re-emitted in form of infra-red radiation or heat and far-red radiation which is known as chlorophyll fluorescence. A reduction in the rate of one process leads to an increase of the other one e.g. a reduction in the dissipation by photochemistry will be reflected in an increase in energy dissipation by non-photochemical processes such as heat and chlorophyll fluorescence (Emerson et al, 1932).

The parameter Fv/Fm describes the maximum quantum efficiency of photosystem II and the photosynthetic performance. It is presented as the ratio of variable fluorescence (Fv) and the maximum fluorescence value (Fm). It is therefore important that measurements are taken at same environmental conditions (Hansatech Handy PEA Manual)

2.7.5 Fruit Quality Parameters

For the analysis of the quality parameters 30 grapes of each treatment and field were picked at the end of the growing season, crushed and analyzed with a fourier transform infrared spectroscopy (FTIR) OenoFoss™. The must weight, the density, the acidity, the pH-value, the amount of tartaric, malic, acetic and gluconic acid and the amount of alpha amino were gained from this analysis.

The must weight was measured as Klosterneuburger Zuckergrade (°KMW). The must weight is a measure of the amount of sugar in grape juice. Hence indicating the amount of alcohol that could be produced if it is all fermented to alcohol, rather than left as residual sugar. While must weight is a commonly used term among wine makers, the physically correct term would be must density.

There was no analysis of the berry weight because of high damage by Peronospora. This infection led to negative effects on yield formation and therefore it was not possible to compare the impact of silicon onto the size of the clusters.

2.8 **Statistical Analysis**

Statistical analysis of the data was made with the software IBM SPSS Statistics 23. All data were tested on normal distribution and homogeneity of variance. A One-Way ANOVA Post Hoc Multiple Comparison test was used by default to determine differences between the treatments. If assumptions of normal distribution and homogeneity of variance were violated, Man-Whitney U Test, a non-parametric test was used.

3 Results

3.1 Assessment of Fungal Diseases

3.1.1 Powdery Mildew

Powdery mildew was assessed on August 11. Prior to this date only few symptoms were visible. Since the first symptoms appeared, the disease has spread rapidly and intensively. Figure 7 shows that up to 50% of the clusters were infested by the fungi in the control groups [V5] and [V6]. Although it seemed that both the rate and the intensity of the infestation were lower in the silicon treated groups, [V1], [V2] and [V3], statistical analysis could not find significant differences. It can be termed as a trend of reduced infections. Noteworthy to mention is the lower rate of infestation in [V2] silicon foliar spray compared to the [V7] common plant protection control group. Although the intensity of infestation in both treatments [V2] and [V7] is at 10 % and the standard error is similar, statistics could not confirm the findings (α=0.05).

For the analysis in Figure 8 data was grouped to increase the sample size and therefore achieve better statistical results. The first bar “silicon” comprises [V1] Si-soil amendment, [V2] Si-foliar spray and [V3] Si-soil amendment and foliar spray. The control groups [V5] and [V6] were merged in “Control”. The sample size for the common plant protection (CPP) remained the same. The analysis of grouped data shows that the silicon treatments tended to perform better for the rate of infestation than the control group, however, the difference was not statistically significant (α=0.05). The decrease of the intensity of infestation relative to the control group was more pronounced and statistically significant (α=0.05) in the CPP treatment. Relative to the control, the intensity of infestation was significantly reduced both in the CPP and silicon. Therefore, silicon treatments can partly substitute for fungicides while maintaining a similar level of fungal symptoms.

For the assessment of fungal symptoms on the leaves (Figure 9) no differences, nor clear trends can be determined. High infections of downy mildew on the leaves aggravated the optical assessment of powdery mildew. From Figure 9 it can be concluded that no treatment attains better results in the sense of a lower infection of the leaves.

3.1.2 Downy Mildew

Downy mildew was assessed twice on June 24 and August 11. At the first time, the rate of infestation for the clusters was below 15% in all treatments (Figure 10), whereas it increased tremendously up to 90% at the second assessment (Figure 11).

The cluster assessment on June 24 shown in Figure 10 does not give evidence that the silicon treatments are superior compared to the control group. Clearly visible is the higher efficiency of the fungicides in CPP control which is secured statistically for both the intensity and rate of infestation. The assessment of the grape clusters on August 11 (Figure 11) shows a similar pattern. Although the difference between CPP and the other treatments decreased for the intensity and the rate of infestation, it is still significant that fungicide application provided better protection for downy mildew regarding the rate of instestaton.

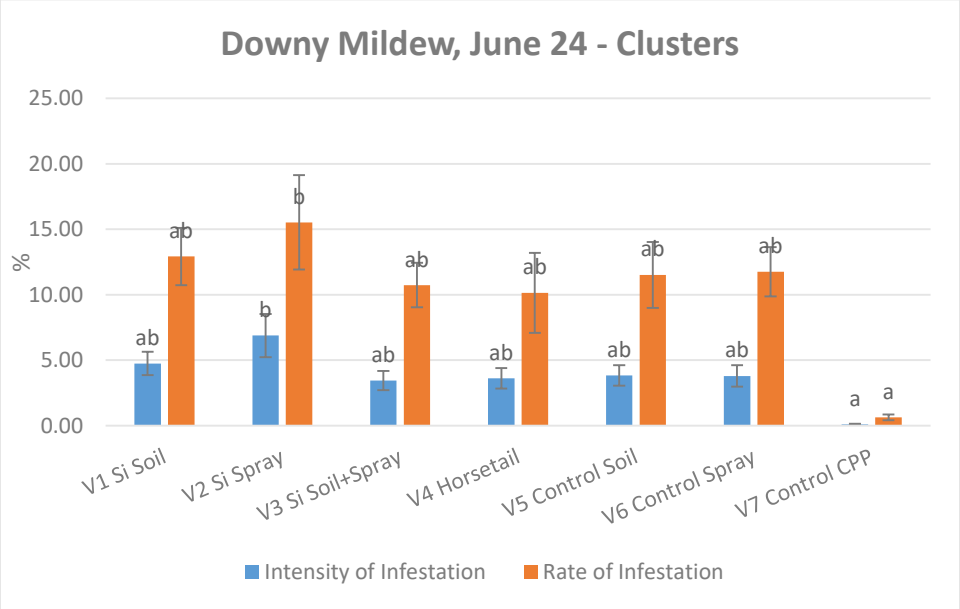

Figure 10: Assessment of downy mildew of grape clusters on June 24, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

3.2 **Silicon Status in Soil**

3.2.1 Plant-Available Silicon

The efficiency of the silicon soil amendment can be clearly seen in Figure 16, where the level of plant-available silicon in the topsoil (0-30 cm) is shown. All results fall within the typical range of 0.029 – 0.175 mM plant-available silicon reported in the literature (Epstein, 1994).

The first bar (T1) indicates the soil analysis before the Si applications. At this time no differences in the level of plant-available silicon could be detected for the treatments. After three Si-applications (T2) the level of plant-available silicon increased in the Si-soil amendment [V1] and the Si-soil amendment + foliar spray [V3] significantly relative to the control group [V6], which remained unchanged. After six Si applications (T3) the level of silicic acid still increased to a higher level and was significantly different to the [V6] control group. Probably due to higher temperatures and thus higher microbial activity and dissolution rates the level of silicic acid also increased in the [V6] control group.

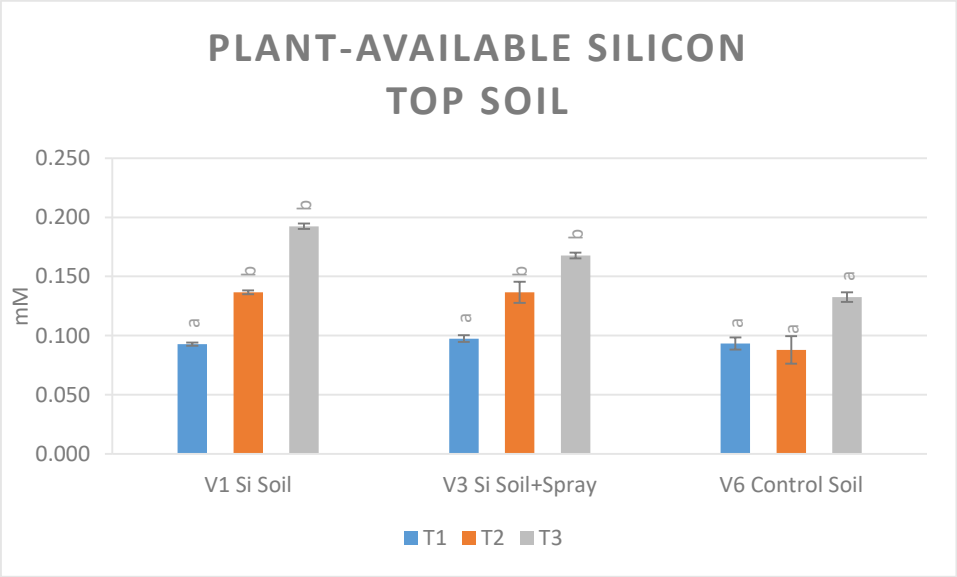

Figure 14: Plant-available silicon in the topsoil, T1: date of sample one on May 17, 2016, T2: date of sample two on July 5, 2016, T3: date of sample three on August 25, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

3.2.2 Amorphous Silicon

The enrichment of the amorphous Si fraction worked well in the topsoil as can be seen in Figure 16. Amorphous Silicon ranges from 1000 to 30000 mg/kg in soil (Epstein, 1994). In the Si-amended soil treatment [V1], the level of amorphous silicon doubled from 1500 mg/kg (T1) to 3000 mg/kg (T3). For the treatment Si-soil + foliar spray treatment [V3] a similar but less pronounced trend was observed. The amount in the control group [V6] remained stable over time.

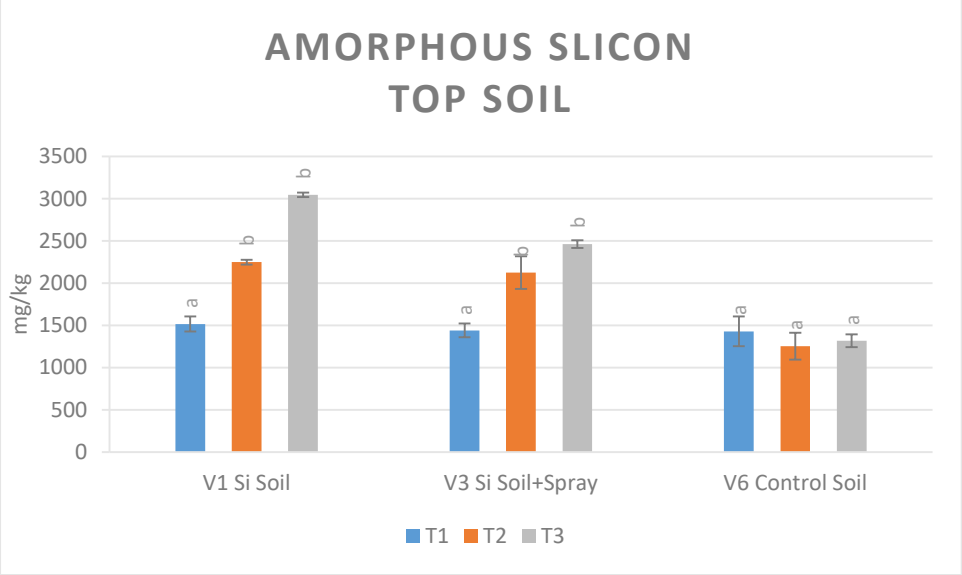

Figure 16: Amorphous silicon in the topsoil, T1: date of sample one on May 17, 2016, T2: date of sample two on July 5, 2016, T3: date of sample three on August 25, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

Significant differences can be found for the subsoil as well (Figure 17). Soil with Si-soil amendments show increased levels of amorphous silicon compared to the control group. Compared to the topsoil the amplitude of the rise is not that high in the subsoil, but clearly visible and statistically significant.

3.3 Leaf Analysis

The Si concentration of mature leaves (Figure 18) increases with leave age. Clearly visible is the boost of Si concentrations in the treatments with foliar spray [V2] and the combined soil amendment + foliar spray [V3]. Since the treatment Si soil amendment [V1] does not show an increased level of Si compared to the control groups, one can conclude that only the foliar spray increased the level of Si in the leaves.

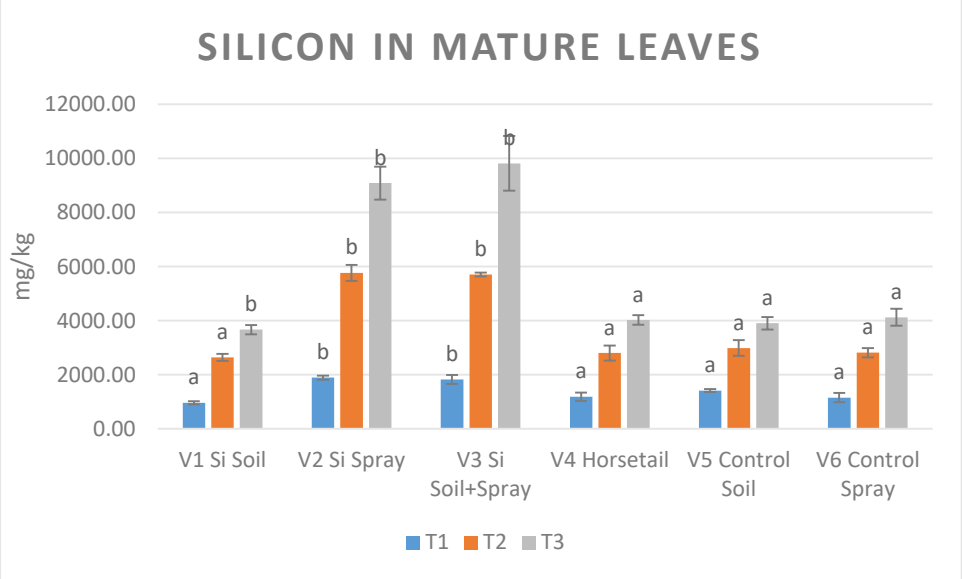

Figure 18: Silicon concentrations of mature grapevine leaves. T1: date of sample one on June 21, 2016, T2: date of sample two on July 20, 2016, T3: date of sample three on August 25, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

The Si level in young leaves was initially much lower at around 200 mg/kg (Figure 19) than for mature leaves which were general > 1000 mg/kg. At time T2, the treatments [V2] and [V3] exceeded 1000 mg/kg also in younger leaved and were statistically distinguishable from the control groups [V5] and [V6]. Surprising is the last sample at T3 where all treatments show highly elevated amounts of Si and the treatments [V2] and [V3] even surpass the Si levels of the mature leaves.

Noteworthy is the significant difference between Si-foliar spray [V2] and the soil amendment + foliar spray [V3] at time T3. Although the soil amendment in [V1] does not show elevated levels of foliar Si, the combination of soil amendment and foliar spray in treatment [V3] seems to further increase the silicon deposits in the leaves.

3.4 **Photosynthesis**

The results of the chlorophyll fluorescence for mature leaves (Figure 20) showed at times T3 and T4 significant reductions in the CPP control group [V7]. The analysis of the chlorophyll fluorescence of young leaves (Figure 21) shows similar results. There is no data in T1 because the first appearing grapevine leaves are included in the mature leaves.

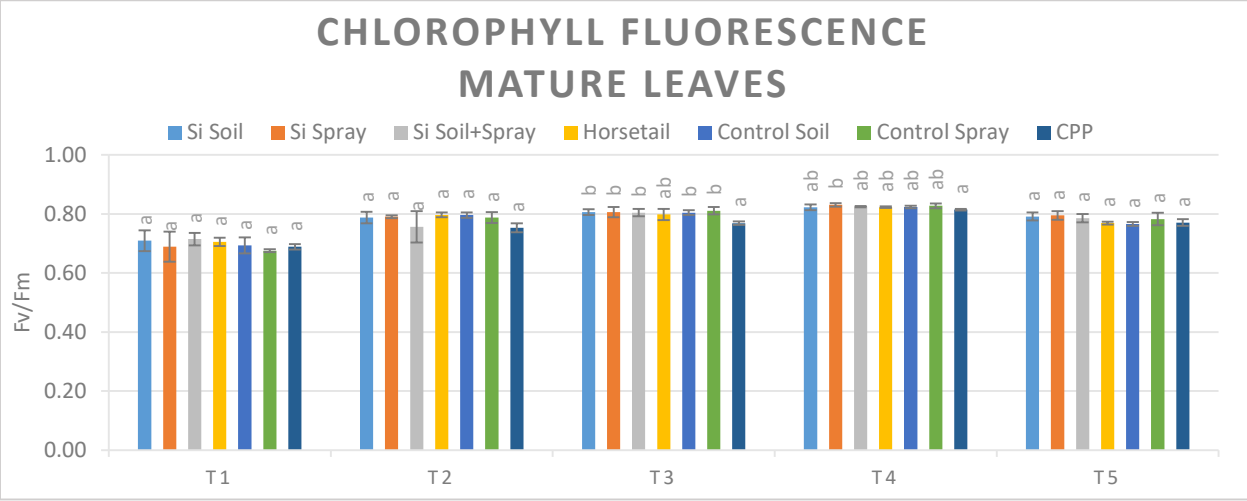

Figure 20: Chlorophyll florescence of mature grapevine leaves, T1: date of sample one on May 30, 2016, T2: date of sample two on June 16, 2016, T3: date of sample three on July 5, 2016, T4: date of sample four July 28, 2016, T5: date of sample five on August 16, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

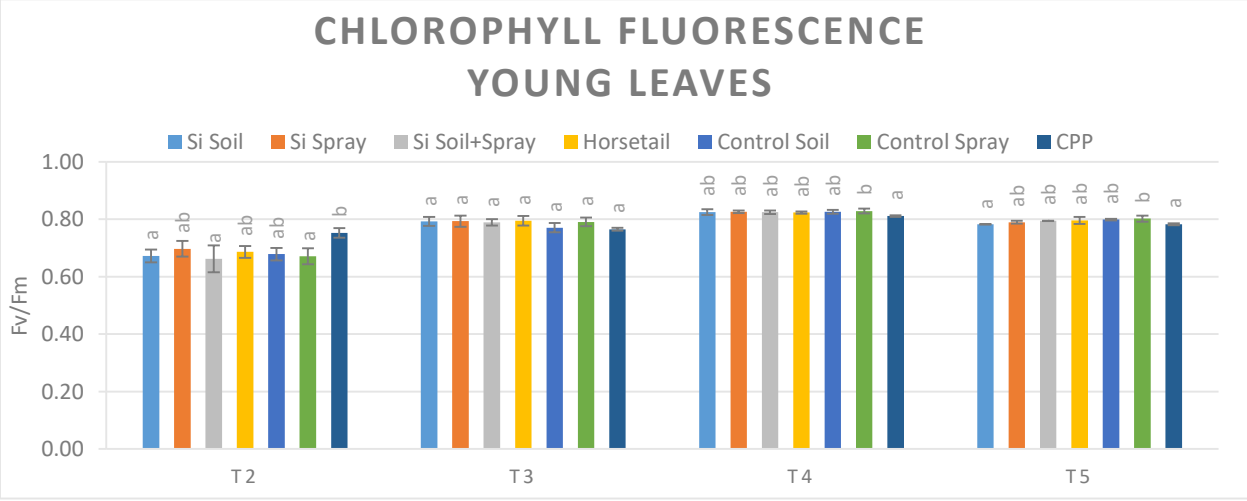

Figure 21: Chlorophyll florescence of young grapevine leaves, T1: date of sample one on May 30, 2016, T2: date of sample two on June 16, 2016, T3: date of sample three on July 5, 2016, T4: date of sample four July 28, 2016, T5: date of sample five on August 16, 2016, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

3.5 Fruit Quality Parameters

The analysis of the fruit quality parameters gives a consistent picture. There is no treatment which enhances the quality of one or more parameters of the fruit juice (Table 7). The only exception is the amount of alpha amino acids (Figure 22) when grouped into categories “Silicon”, “Control” and “CPP”. Silicon treated vines show elevated values of amino acids compared to the control group and CPP.

Treatment	°KMW	Density	pH	Acidity (g/l)	Tartaric Acid (g/l)	Malic Acid (g/l)	Acetic Acid (g/l)	Gluconic Acid (g/l)	Alpha Amino (mg/l)
V1	15.73	1.08	3.10	8.73	7.74	3.34	0.01	0.56	193.60
V2	15.98	1.08	3.11	9.05	7.81	3.79	0.04	0.56	192.90
V3	15.78	1.17	3.12	8.83	7.73	3.66	0.03	0.65	186.18
V4	15.93	1.08	3.12	8.93	7.80	3.74	0.04	0.60	188.65
V5	15.83	1.08	3.09	9.14	7.96	3.80	0.03	0.53	175.74
V6	15.33	1.08	3.11	8.96	7.65	3.61	0.02	0.49	180.61
V7	15.35	1.16	3.12	8.65	7.59	3.34	0.03	0.44	157.39

Table 10: Means of fruit quality parameters

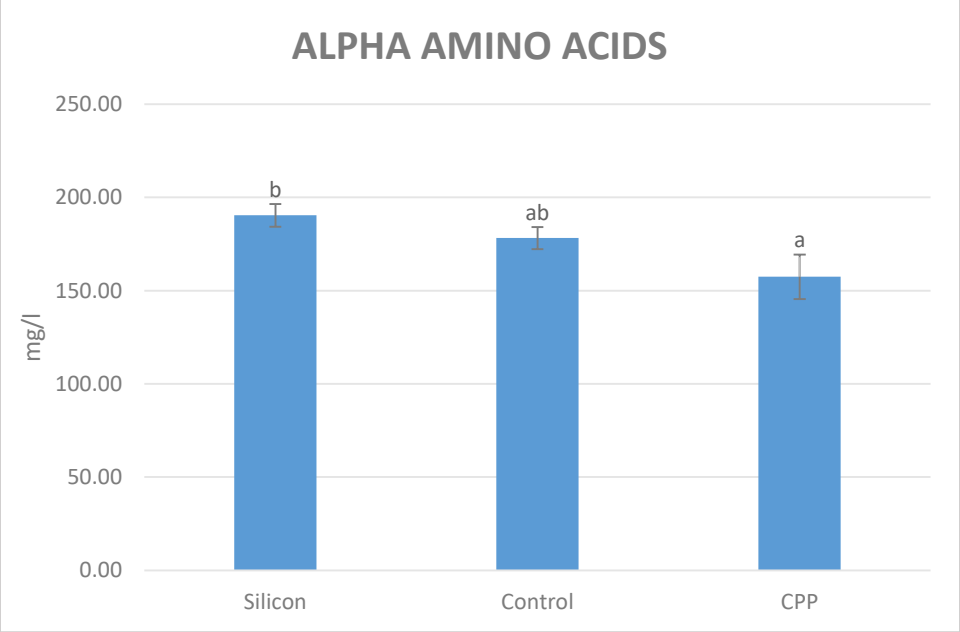

Figure 22: Analysis of alpha amino acids in the fruit juice, One-Way ANOVA Post Hoc Multiple Comparison test was used to determine differences between the treatments, different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis, error bars represent standard error of the mean different letters above columns indicate significant differences between treatments, α=0.05, at the same time point of analysis

6 Appendix

6.1 EPPO Standard Uncinula necator PP 1/4(4)

European and Mediterranean Plant Protection Organization
Organisation Européenne et Méditerranéenne pour la Protection des Plantes

PP 1/4(4)

Efficacy evaluation of fungicides
Uncinula necator

Specific scope
This standard describes the conduct of trials for the efficacy evaluation of fungicides against *Uncinula necator*, causing powdery mildew of grapevine.

Specific approval and amendment
First approved in 1977-09.
Revision approved in 1987-09.
Aligned with revised standard text in 1996.
Revision approved in 2001-09.

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1. Experimental conditions

1.1 Test organisms, selection of crop and cultivar

Test organism: *Uncinula necator* (UNCINE).
Only productive grapevine *Vitis vinifera* (VITVI) of the same susceptible cultivar, rootstock habit and age, should be used.

1.2 Trial conditions

The trial should be set up in the field. The vineyard should be homogeneous in cultivar, age, plant width, training system, rootstock and general cultivation and health status. Cultural conditions (e.g. soil type, fertilization) should be uniform for all plots of the trial and should conform with local agricultural practice. Microclimate conditions should as far as possible be homogeneous, particularly with respect to altitude, slope and wind exposure. The trial should form part of a trial series carried out in different regions with distinct environmental conditions
and preferably in different years or growing seasons (see EPPO Standard PP 1/181 Conduct and reporting of efficacy evaluation trials).

1.3 Design and lay-out of the trial

Treatments: test product(s), reference product and untreated control, arranged in a suitable statistical design. Plot size (net): at least 10 vines (or sufficient to provide at least 100 leaves and at least 50 bunches for assessment, as in 3.2) on 3 rows. Sample size may be increased (e.g. 150 leaves and 100 bunches) if the intensity of the disease is not expected to be high. Replicates: at least 4. For further information on trial

2. Application of treatments

2.1 Test product(s)

The product(s) under investigation should be the named formulated product(s) (see EPPO Standard PP 1/181 Conduct and reporting of efficacy evaluation trials).

2.2 Reference product

The reference product should be a product known to be satisfactory in practice under the agricultural, plant health and environmental (including climatic) conditions in the area of intended use. In general, type of action, time of application and method of application should be as close as possible to those of the test product.

2.3 Mode of application

Applications should comply with good standard practice.

2.3.1 Type of application
The type of application (e.g. a spray or a dust) should be as specified for the intended use.

2.3.2 Type of equipment
Application(s) should be made with equipment which provides an even distribution of product on the whole plot or accurate directional application where appropriate, equivalent to good commercial practice. Factors which may affect efficacy (such as operating pressure, nozzle type) should be chosen in relation to the intended use.

6.2 EPPO Standard Plasmopara viticola PP 1/4(4)

European and Mediterranean Plant Protection Organization
Organisation Européenne et méditerranéenne pour la Protection des Plantes

PP 1/31(3)

Efficacy evaluation of fungicides
Plasmopara viticola

Specific scope
This standard describes the conduct of trials for the efficacy evaluation of fungicides against *Plasmopara viticola*, causing downy mildew of grapevine.

Specific approval and amendment
First approved in 1980-09.
Aligned with revised standard text in 1996.
Revision approved in 2000-09.

1. Experimental conditions

1.1 *Test organisms, selection of crop and cultivar*

Test organism: *Plasmopara viticola* (PLASVI).
Crop: grapevine *Vitis vinifera* (VITVI).

1.2 *Trial conditions*

The trial should be set up in the field in productive vineyards with natural infection but, in certain circumstances, it may be necessary to carry out the trial on special small plots, with artificial inoculation and misting in order to enhance infection. Cultural conditions (e.g. soil type, fertilization) should be uniform for all plots of the trial and should conform with local viticultural practice. The trial should preferably be set up in a topographically and climatically homogeneous environment favorable to the pathogen. The trial should form part of a trial series carried out in different regions with distinct environmental conditions and preferably in different years or growing seasons (see EPPO Standard PP 1/181 Conduct and reporting of efficacy evaluation trials).

1.3 *Design and lay-out of the trial*

Treatments: test product(s), reference product and untreated control, arranged in a suitable statistical design. Plot size (net): sufficient to provide at least 100 bunches per plot for natural infection or 50 bunches per plot when artificial inoculation is used.
Replicates: at least 4. For further information on trial design, see EPPO Standard PP 1/152 Design and analysis of efficacy evaluation trials.

2. Application of treatments

2.1 *Test product(s)*

The product(s) under investigation should be the named formulated product(s) (see EPPO Standard PP 1/181 Conduct and reporting of efficacy evaluation trials).

2.2 *Reference product*

The reference product should be a product known to be satisfactory in practice under the agricultural, plant health and environmental (including climatic) conditions in the area of intended use. In general, type of action, time of application and method of application should be as close as possible to those of the test product.

2.3 *Mode of application*
Applications should comply with good standard practice.

2.3.1 *Type of application*
The type of application (e.g. a spray) should be as specified for the intended use.

2.3.2 *Type of equipment*
Application(s) should be made with equipment which provides an even distribution of product on the whole plot or accurate directional application where appropriate, equivalent to a good commercial practice. Factors which may affect efficacy (such as operating pressure, nozzle type) should be chosen in relation to the intended use.

2.3.3 *Time and frequency of application*
The number of applications and the date of each application should be as specified for the intended use.

6.3 Evaluation Form

Auswerteformular

Krems,

Botrytis	Penicillium	Essigfäule
Peronospora	Schwarzfäule	Oidium
Sonnenbrand	Stiellähme	Traubenwelke

Traubenbefall	1	2	3	4	5	6	7
Variante	0%	0-5 %	6- 10 %	11- 25 %	26-50 %	51-75 %	>75 %

Traubenbefall	1	2	3	4	5	6	7
Variante	0%	0-5 %	6- 10 %	11- 25 %	26-50 %	51-75 %	>75 %

Traubenbefall	1	2	3	4	5	6	7
Variante	0%	0-5 %	6- 10 %	11- 25 %	26-50 %	51-75 %	>75 %

Traubenbefall	1	2	3	4	5	6	7
Variante	0%	0-5 %	6- 10 %	11- 25 %	26-50 %	51-75 %	>75 %

auswerteformular_befallsgrad Seitennummer - -

6.4 BBCH-Scale for Grapevine

Growth stage	Code	Description
0: Sprouting/Bud development	00	Dormancy: winter buds pointed to rounded, light or dark brown according to cultivar; bud scales more or less closed according to cultivar
	01	Beginning of bud swelling: buds begin to expand inside the bud scales
	03	End of bud swelling: buds swollen, but not green
	05	"Wool stage": brown wool clearly visible
	07	Beginning of bud burst: green shoot tips just visible
	09	Bud burst: green shoot tips clearly visible
1: Leaf development	11	First leaf unfolded and spread away from shoot
	12	2nd leaves unfolded
	13	3rd leaves unfolded
	19	9 or more leaves unfolded
5: Inflorescence emerge	53	Inflorescences clearly visible
	55	Inflorescences swelling, flowers closely pressed together
	57	Inflorescences fully developed; flowers separating
6: Flowering	60	First flowerhoods detached from the receptacle
	61	Beginning of flowering: 10% of flowerhoods fallen
	62	20% of flowerhoods fallen
	63	Early flowering: 30% of flowerhoods fallen
	64	40% of flowerhoods fallen
	65	Full flowering: 50% of flowerhoods fallen
	66	60% of flowerhoods fallen
	67	70% of flowerhoods fallen
	68	80% of flowerhoods fallen
	69	End of flowering
7: Development of fruits	71	Fruit set: young fruits begin to swell, remains of flowers lost
	73	Berries groat-sized, bunches begin to hang
	75	Berries pea-sized, bunches hang
	77	Berries beginning to touch
	79	Majority of berries touching
8: Ripening of berries	81	Beginning of ripening: berries begin to develop variety-specific colour
	83	Berries developing colour
	85	Softening of berries
	89	Berries ripe for harvest
9: Senescence	91	After harvest; end of wood maturation

6.5 Powdery Mildew VitiMeteo Prognostic Data

ViTiMeteo
Agroscope
Staatliches Weinbauinstitut Freiburg
GEOsens Softwareentwicklung

Prognose für Oidium und Rebwachstum

Eine Gemeinschaftsentwicklung von Agroscope Changins- Wädenswil und Staatlichem Weinbauinstitut Freiburg (D)
Berechnung: Oidium nach Oidiag 2.2, Dr. Walter Kast, LVWO Weinsberg; Rebwachstum nach Prof. Dr. H. Schultz, FA Geisenheim

Station: Krems-Landersdorf, 01.01.2016 - 01.10.2016

Erstellt: 26.09.2016 12:54:38 Wetterdaten bis: 26.09.2016 11:15 Vorhersage bis: 01.10.2016 11:00

Austrieb: 20.04.2016 00:00 Wachstum angegeben für: Durschschnittsrebsorte pro Haupttrieb (ohne Geiztriebe)

Datum	Oidium-Index	Risiko	Temperatur °C Min	Ø	Max	Niederschlag mm	Wachstum Blattzahl	Blattfläche cm²	Bemerkungen
01.01.2016	0 %	!	-3,3	-1,0	3,3	0,4	0	0	
02.01.2016	0 %	!	-3,9	-1,7	0,7	0,0	0	0	
03.01.2016	0 %	!	-5,7	-5,1	-4,0	0,0	0	0	
04.01.2016	0 %	!	-7,5	-5,8	-4,6	0,0	0	0	
05.01.2016	0 %	!	-10,2	-6,2	-4,1	0,0	0	0	
06.01.2016	0 %	!	-5,9	-4,3	-2,4	0,0	0	0	
07.01.2016	0 %	!	-8,5	-2,2	2,5	2,0	0	0	
08.01.2016	0 %	!	-6,4	1,2	9,4	0,2	0	0	
09.01.2016	0 %	!	-2,4	0,2	1,8	1,8	0	0	
10.01.2016	0 %	!	0,0	0,9	1,9	2,0	0	0	
11.01.2016	0 %	!	0,4	2,7	7,6	0,2	0	0	
12.01.2016	0 %	!	-1,9	5,6	9,6	0,0	0	0	
13.01.2016	0 %	!	3,2	5,3	8,0	0,0	0	0	
14.01.2016	0 %	!	-3,3	2,4	8,4	0,0	0	0	
15.01.2016	0 %	!	-2,0	1,9	5,4	0,0	0	0	
16.01.2016	0 %	!	-3,3	0,3	1,6	0,0	0	0	
17.01.2016	0 %	!	-8,4	-2,7	-0,6	0,0	0	0	
18.01.2016	0 %	!	-9,9	-4,6	0,9	0,8	0	0	
19.01.2016	0 %	!	-11,4	-7,7	-1,7	0,0	0	0	
20.01.2016	0 %	!	-13,0	-4,9	2,0	0,0	0	0	
21.01.2016	0 %	!	-8,6	-2,6	0,8	0,0	0	0	
22.01.2016	0 %	!	-11,9	-7,3	-1,1	0,0	0	0	
23.01.2016	0 %	!	-11,9	-6,9	-0,3	0,0	0	0	
24.01.2016	0 %	!	-2,8	1,7	7,6	3,2	0	0	
25.01.2016	0 %	!	-2,4	3,3	6,1	3,4	0	0	
26.01.2016	0 %	!	-2,4	3,8	11,7	0,0	0	0	
27.01.2016	0 %	!	-3,4	2,0	10,3	0,0	0	0	
28.01.2016	0 %	!	2,1	7,7	17,5	0,0	0	0	
29.01.2016	0 %	!	-2,0	4,6	11,9	6,0	0	0	
30.01.2016	0 %	!	-3,7	3,0	13,1	0,0	0	0	
31.01.2016	0 %	!	0,2	5,3	8,9	0,0	0	0	
01.02.2016	0 %	!	2,8	8,5	14,9	4,0	0	0	
02.02.2016	0 %	!	0,1	8,1	13,3	0,0	0	0	
03.02.2016	0 %	!	0,5	5,9	10,5	5,2	0	0	
04.02.2016	0 %	!	-1,4	3,4	6,8	0,0	0	0	
05.02.2016	0 %	!	-1,1	3,8	8,8	0,0	0	0	

6.6 Downy Mildew VitiMeteo Prognostic Data

VitiMeteo
Agroscope
Staatiches Weinbauinstitut Freiburg
GEOsens Softwareentwicklung

Detaillierte Prognose für Plasmopara viticola und Rebwachstum

Eine Gemeinschaftsentwicklung von Agroscope CH (RAC Changins, FAW Wädenswil) und Staatl. Weinbauinstitut Freiburg (D)
Berechnung: Sporangiendichte nach Dr. G. Hill, DLR Oppenheim; Rebwachstum nach Prof. Dr. H. Schultz, FA Geisenheim

Station: Krems-Landersdorf, 01.01.2016 - 01.10.2016

Erstellt: 26.09.2016 12:06:48 Wetterdaten bis: 26.09.2016 11:15 Vorhersage bis: 01.10.2016 11:00

Keimbereitschaft: 11.05.2016
Austrieb: 20.04.2016

Wachstum angegeben für: pro Haupttrieb (ohne Geiztriebe)

Durchschnittsrebsorte

Datum	Sporulation	Sporangiendichte	Infektion	Inkubation 26.09.	Inkubation 01.10.	Temperatur °C Min.	Temperatur °C Ø	Temperatur °C Max.	Niederschlag mm	Blattnässe Std.	Blattnässe Grad-std. bei BN.	Wachstum Blattzahl	Wachstum Blattfläche cm²	Bemerkungen
01.01.						-3,3	-1,0	3,3	0,4	3				
02.01.						-3,9	-1,7	0,7		2				
03.01.						-5,7	-5,1	-4,0						
04.01.						-7,5	-5,8	-4,6						
05.01.						-10,2	-6,2	-4,1						
06.01.						-5,9	-4,3	-2,4						
07.01.						-8,5	-2,2	2,5	2,0	1				
08.01.						-6,4	1,2	9,4	0,2	3	15			
09.01.						-2,4	0,2	1,8	1,8	10	5			
10.01.						0,0	0,9	1,9	2,0	16	6			
11.01.						0,4	2,7	7,6	0,2	11	10			
12.01.						-1,9	5,6	9,6		2	6			
13.01.						3,2	5,3	8,0		2	4			
14.01.						-3,3	2,4	8,4		2	3			
15.01.						-2,0	1,9	5,4			1			
16.01.						-3,3	0,3	1,6						
17.01.						-8,4	-2,7	-0,6		10				
18.01.						-9,9	-4,6	0,9	0,8	10				
19.01.						-11,4	-7,7	-1,7						
20.01.						-13,0	-4,9	2,0						
21.01.						-8,6	-2,6	0,8						
22.01.						-11,9	-7,3	-1,1						
23.01.						-11,9	-6,9	-0,3		15				
24.01.						-2,8	1,7	7,6	3,2	7	2			
25.01.						-2,4	3,3	6,1	3,4	18	50			
26.01.						-2,4	3,8	11,7						
27.01.						-3,4	2,0	10,3		4	15			
28.01.						2,1	7,7	17,5		1	4			
29.01.						-2,0	4,6	11,9	6,0	12	36			
30.01.						-3,7	3,0	13,1		3	19			
31.01.						0,2	5,3	8,9		9	17			
01.02.						2,8	8,5	14,9	4,0	11	44			
02.02.						0,1	8,1	13,3						
03.02.						0,5	5,9	10,5	5,2	11	19			

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6.7 $CaCl_2$ Extraction of Plant-Available Silicon on Soils

(modified from Haysom and Chapman, 1975 and Liang et al., 2015)

SERVES
10 samples in duplicate

20 MINUTES
16 HOURS SHAKING

2g air-dried soil

0.01M $CaCl_2$ SOLUTION

1 Liter HQ Water

1.4702g calcium chloride

As the total Si content is not related to the concentration of soluble Si in soils and can provide little information on soil Si availability to plants, this method is developed to extract plant-available Si from soils.

For the preparation of the 0.01M solution add the calcium chloride to the HQ Water.

Put 2g of air-dried soil (<2mm) into a 50-ml polyethylene tube and by pipette, add 20ml of the 0.01M $CaCl_2$ solution to the tube. Shake this for 16 hours in an overhead shaker and filtrate it with Munktell Ahlstrom paper filters with a grade of 14/N.

6.8 NaOH Extraction of Amorphous Silica in Soils

(modified from Georgiadis et al., 2015)

SERVES
25 samples in duplicate

121 HOURS

25mg of ground soil

0.2M NaOH SOLUTION

8g Sodium hydroxide
1 Liter HQ water

A solution of 0.2 M NaOH almost completely extracts amorphous silica, and when applied at room temperature and a solid: solution ratio of 1:400, only slightly brakes down crystalline Si compounds. The predictable and reproducible underestimation was considered more acceptable than the variable partial dissolution of silicates that occurs during extraction at higher temperatures. It is recommended using this method on soils from temperate-humid climate to estimate the amorphous Si fraction.

Before starting with the procedure it is important to calculate the water content of the soil. Therefore, weigh the wet and dry weight of the soil samples. Dry them at 105°C for 48 hours. The water content is calculated as a ratio of the weight of the evaporated water and the weight of the wet soil (wc = wH_20 / wwet)

Prepare the NaOH solution and grind you soil samples in a Retsch Ball Mill for 10min. In a 100ml calibrated flask, add the 0.2M sodium hydroxide solution in a ratio of 1:400 to it. Use a balance for determining the exact amount.

Afterwards shake the samples for 120 hours in an overhead shaker at room temperature and filtrate the samples with Munktell Ahlstrom paper filters with a grade of 14/N.

6.9 Adsorptiometric Determination of Silicon

(modified from Morrison and Wilson, 1963)

SERVES

10 samples in duplicate

1 HOUR 30 MINUTES

A method together with a modification for obtaining high sensitivity for determining plant-available silicon in soil. It is based on the absorptiometric measurement of solutions of reduced β-molybdosilicic acid. The limit of detection was about 0.001 ppm of silica.

Soil extraction samples (see $CaCl_2$ extraction or NaOH extraction)

HQ Water

Tartaric acid

ACIDIFIED MOLYBDATE SOLUTION

89g ammonium molybdate

62ml of 98% sulphuric acid

REDUCING AGENT

1.2g sodium sulphite

0.2g 4-amino-3-hydroxy-1-naphthalenesulphonic acid (purest grad available)

14g potassium disulphite

STANDARD SOLUTIONS OF SILICA

1000g pure dry silica

5g anhydrous sodium carbonate

All reagents should be of analytical grade unless otherwise stated. Start with the acidified molybdate solution and dissolve the ammonium molybdate in about 800 ml of water at room temperature. Dilute the sulphuric acid to about 100ml by adding it cautiously to water, with stirring, and allow to cool. Add the acid to the molybdate solution and dilute to 1 liter. The reagent may be kept for several months.

Make a 28 per cent. *w/v* solution with the tartaric acid. It can be kept for at least 3 months. For the reducing agent dissolve the sodium sulphite and 4-amino-3-hydroxy-1-naphthalenesulphonic acid in about 70ml of water. Add the potassium disulphite and shake well until dissolved and dilute to 100ml. This reagent should be freshly prepared each week.

For the standard solutions of silica fuse the pure dry silica with the anhydrous sodium carbonate in a platinum crucible at red heat. When cool, dissolve in water and dilute to exactly 1 liter. This solution contains 1000 ppm of silica. Prepare different solutions of silica by diluting. The solutions are stable for at least 3 months.

By pipette place 0.4ml of your extraction samples in 100ml calibrated flasks. Add 16ml of HQ water and 1ml of acidified molybdate solution. 10 minutes later ±3 minutes add 1ml of tartaric acid and wait for 5 minutes ±1 minute before proceeding. 0.5ml of the reducing agent is added and some samples might already become blueish. Fill up the flasks with 1.1ml to a 20ml solution. Wait one hour before measuring the optical density with a photometer.

Use the prepared standard solution to get a calibration curve of the photometer. The blank solution should contain 80ml of water of the same batch as was used for the preparing and diluting the standards. From the obtained results prepare a calibration curve.

6.10 NaOH Extraction of Amorphous Silica in Plants

(modified from Elliot and Snyder, 1991)

SERVES
24 samples in duplicate

3 HOURS

Many methodologies for the determination of Si in plant tissue are tedious and slow and/or involve cumbersome safety precautions. This new autoclave-induced digestions (AID) method has been developed to make plant tissue extraction easier. The method is linearly correlated with Si determination by NaOH fusion.

100mg ground plant tissue

HQ water

50% H_2O_2

50% NaOH SOLUTION

100mg of ground plant tissue is wetted with 2ml of 50% H_2O_2 in 100-ml polyethylene tubes. Add 4.5g of 50% NaOH solution and vortex the tubes gently.

The tubes were covered with lose fitting plastic caps and samples were placed in an autoclave at 121°C with a sterilization phase of 20 minutes. Afterwards when cooled down the content is filled up with HQ water to 50ml and samples are centrifuged at 1000 g for 5 minutes at room temperature.

Eextracts were analyzed colorimetrically with a Varian DMS 200 UV visible spectrophotometer (see 6.9 Adsorptiometric Determination of Silicon).

6.11 LUDOX TM50 Colloidal Silica

SIGMA-ALDRICH®

sigma-aldrich.com

3050 Spruce Street, Saint Louis, MO 63103, USA
Website: www.sigmaaldrich.com
Email USA: techserv@sial.com
Outside USA: eurtechserv@sial.com

Product Specification

Product Name:
LUDOX® TM-50 colloidal silica 50 wt. % suspension in H_2O

Product Number: **420778**

SiO_2

MDL: MFCD00011232
Formula: O2Si
Formula Weight: 60.08 g/mol

TEST	Specification
Appearance (Form)	Viscous Liquid
Appearance (Clarity) Cloudy	Conforms
pH At 25℃	8.5- 9.5
Viscosity At 25℃	≤55 cps
Specific Gravity At 60℉	1.388- 1.407
Silica	49.0- 51.0 %
Ratio SiO2:Na2O	200- 250
m2/g (Surface Area)	110- 150
Sulfates (SO4) As Na2SO4	≤0.135 %
Assay % Transmittance	≥20 %
Note Ludox TM-50	Confirmed

Remarks:
Specification Date : 11/29/2010

6.12 **Equisetum Plus**

Produktinformationen

Equisetum Plus

Art-Nr.: 20005

Pflanzenhilfs- & Pflanzenstärkungsmittel
Gemüsebau
Weinbau
Obstbau

Hoch konzentrierter Schachtelhalmextrakt (Equisetum arvense)

Equisetum Plus ist ein Schachtelhalmextrakt (*Equisetum arvense*) in welchem als Hauptbestandteile pflanzliche Kieselsaure und Schwefelverbindungen enthalten sind.

Wirkungsweise:
Aufgrund seines hohen Siliziumgehaltes fördert Equisetum Plus die bessere Ernährung und Kräftigung der Pflanze. Natürliche Kieselsäure wird verstärkt in die Zellwände eingelagert (Verkieselung). Dies festigt Zellwände und Epidermis und stärkt somit die Pflanzen gegenüber abiotischem Stress. Entscheidend für den Behandlungserfolg ist eine regelmäßige Anwendung während der gesamten Vegetation.

Anwendung:
Kernobst: 1 %ig ab Mitte August; 3–4 Anwendungen (3–4 l pro ha)
Reben: 1 %ig; 2 Anwendungen vor der Blüte, nach der Blüte 3–4 Anwendungen
Gemüse: 1 %ig in regelmäßigem Abstand

Anwendungshinweise:
Equisetum Plus ist sowohl zum Gießen als auch zum Spritzen mit den üblichen Spritz- und Sprühverfahren geeignet.
Zur Bodenbehandlung die Erde gut überbrausen.
Zur Pflanzenbehandlung die Pflanzen von allen Seiten benetzen.
Es empfiehlt sich bei Sonnenschein zu spritzen; ein schnelles Antrocknen unterstützt die pflanzenstärkende Wirkung.
Unverträglichkeiten sind nicht bekannt.

Weitere Informationen

Sicherheitsdatenblatt: Equisetum plus SDB_D.pdf
Sicherheitsdatenblatt CLP: SDB Insecto_Sec_AT 201505192.pdf
Zusatz: Schachtelhalmextrakt
Gebindegrößen: 10 und 25 Liter
infoxgen: 1