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The Effects of Several Forms of Leaf Area Management and Different Canopy Heights with Vertical Shoot Positioning on Berry Ripening and Wine Quality

Die Auswirkungen verschiedener Formen der Laubwandbehandlung sowie unterschiedlicher Laubwandhöhen in Spalieranlagen auf die Beerenreife und die Qualität der Weine

L'effetto di diverse forme di gestione e altezza della parete fogliare in sistemi di allevamento a spalliera sulla maturazione dell'uva e la qualità dei vini

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ABSTRACT

The goal of this research was to investigate different canopy heights and canopy management approaches in VSP-trained vineyards on the production of sugar and other substances present in berries and must, as well as on the resulting wine quality. Two sites, one high vigour and one low vigour, were selected for this study, with the following treatments tested: 'control', shoots were topped according to standard practices; 'without lateral shoots', all lateral shoots were removed; 'low canopy', the canopy was shortened to 50 cm below the height of the 'control'; 'twisted shoots', shoots were not hedged, but instead were horizontally twisted along the upper wires. The 'low canopy' treatment revealed little effect on grape ripening parameters, especially in the low vigour trials. Upon sensory analysis, the quality of wine derived from this treatment did not score higher than the control, but instead consistently lower. Furthermore, 'low canopy' wines exhibited atypical ageing notes, and in certain vintages more berry shrivel was observed during the vegetative season. The 'twisted shoots' treatment displayed consistently higher YAN values in the must, especially in vineyards with higher vigour, which led to an increase in potential vine fertility. Thus, shortening the canopy was not found to be a suitable technique for delaying ripening or improving wine quality.

KEYWORDS

Wine grape, canopy height, wine quality

CITE ARTICLE AS

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INTRODUCTION

In many grape-growing regions of the world, climate change is causing grapes to mature noticeably earlier [1] [2]. In the Alpine region, this development is especially prominent, with a significantly above-average temperature increase of 1.9 °C recorded between 1920 and 2010 [3]. In many years, in the case of traditional grape varieties, this leads to extremely ripe berries with often very high sugar contents. Wines with an alcohol content of more than 14% by volume are currently accepted by the market, but a segment of consumers would prefer fresher and fruitier wines with a lower alcohol content. In South Tyrol (which is located in the Alpine region of northern Italy), a shifting of individual varieties of grapes to higher elevations is observable as a result of climate change. This poses the question as to what, in future, should be cultivated in the warmer and lower vineyards of the grape-growing area, at elevations of around 200-300 m a.s.l., with a mean temperature during the growing season (April-October) of 17.5 °C (long-term average)? To be sure, there are no definitive studies indicating the temperature above which it is no longer possible to obtain interesting wines from traditional white wine grapes, but current knowledge would suggest that the cultivation of such grape varieties becomes problematic from average temperatures of 17.5 to 18 °C during the vegetation period [4]. In these wine-growing locations in South Tyrol, the white wine varieties of *Ruländer* and *Chardonnay* currently dominate alongside the local red wine varieties of *Vernatsch* and *Lagrein*. Various authors have succeeded in attaining a more or less pronounced delay in the onset of maturation in different locations by reducing leaf area [5] [6] [7] [8]. The purpose of this paper is thus to investigate the extent to which this also applies to South Tyrol, in those portions of the grape-growing area where the cultivation of white wine varieties is increasingly reaching the climatic limit.

In the process, the effects of different forms of leaf area management on wine quality were also determined, insofar as it is well known that a sufficiently large leaf area is a basic prerequisite for high-quality wines [9]. It is desirable to achieve a lower alcohol content especially if there is no concomitant decrease in quality.

If reduced leaf area is achieved by means of more intense shoot topping, more prolific laterals (side shoots) in combination with a denser canopy – at least partially, depending upon the conditions for further leaf growth – must be expected [10]; this is because, as is well known, the decapitation of the shoots promotes the growth of side shoots due to the temporary lack of apical dominance. However, a leaf can assimilate nutrients in an optimal range if it receives at least some sunlight [11]. Largely shaded leaves within the leaf area display a reduced ability to metabolise; they change their mineral metabolism and that of the berries by enriching themselves with more calcium [12]. Further, due to their lower exposure to sunlight and slower drying-out after precipitation, they are susceptible to fungal diseases [13]. For this reason, low leaf areas with a vertical shoot positioning training system (VSP) should not result in significantly stronger growth of lateral shoots and leaves. One possible alternative to low leaf area is the cultivation of a higher, but much looser canopy. High but loose foliage cover of this nature can be achieved in the long term by removing all the lateral shoots at and above the bunch zone. This canopy management technique necessitates a high investment of labour but is particularly popular in vineyards employing organic cultivation methods in order to prevent the after-growth of leaves as far as possible, or at least to avoid their proliferation at the berry zone. This reduces the probability of renewed infection by Plasmopara around the berries.

As already shown, the topping of the shoots (also known as "heading") when managing the leaf area is associated with certain accompanying symptoms. This measure can trigger further shoot growth; the resultant proliferation of lateral shoots can lead to a denser canopy. If no topping is undertaken at all and the shoots begin to droop, this likewise will shade the main leaves; high growth can also make the alleyways impassable.

For this reason, the changes that occur when no heading is undertaken in the vertical shoot positioning system and the shoots are twisted around the upper pair of wires must be considered. This method is increasing in popularity in quality-oriented vineyards worldwide and was therefore subjected to closer scrutiny in this study.

The very heterogeneous topography and soil types in South Tyrol and generally in the north of Italy lead to the vines displaying very different vegetative growing intensities. High vigour situations can be found on deep talus at the foot of the mountains and flatter chains of low foothills, whereas very meagre growth is typical of steep slopes and mountainsides and in the often-shallow soils of flat hilltops. Therefore, one goal of the present study was to investigate the effects of leaf management techniques in different situations of vine growth vigour.

In poor soils, spurts in growth due to decapitation and the resultant higher density of the canopy cannot be expected – or only to a limited extent. That is because, in such locations, vegetative growth is generally appreciably weaker and stops sooner. It is thus possible that deviating results may be found here in comparison with vineyards where growth is more vigorous.

One important aspect of the investigations was to determine the long-term effect of low leaf area on shoot fertility (fruit-bearing performance). As a result of the sometimes early onset and prolonged hot and dry weather phases, in South Tyrolean viticulture years with very low yields are frequent. If the already very moderate yields sought in the quality wine-growing segment are no longer regularly achieved, this could be an issue for the survival of the vineyards in our growing area, which are predominately small to midsize.

The goal of this paper was to investigate the effects of different forms of leaf area management in VSP-trained vineyards on the production of sugar and other substances present in the berries and musts and upon the resultant wine quality. This was done in a wine-growing area in which the cultivation of white wine varieties is being increasingly affected by rising temperatures due to climate change and the production of high-quality white wines is thus under threat.

MATERIALS AND METHODS

EXPERIMENTAL VINEYARDS

Four vineyards in the area surrounding the Laimburg Research Centre were selected for this experiment. Between 2009 and 2011, two of the vineyards characterised by vigorous vegetative growth and planted with *Chardonnay* and *Gewürztraminer* were agronomically described and then micro-vinified (Laimburg location: 46° 22’ 54.048" N, 11° 17’ 8.52" E). Between 2012 and 2014, two sites displaying low vegetative vigour (Kaltern location: 46° 24’ 12.089" N, 11° 15’ 5.454" E)

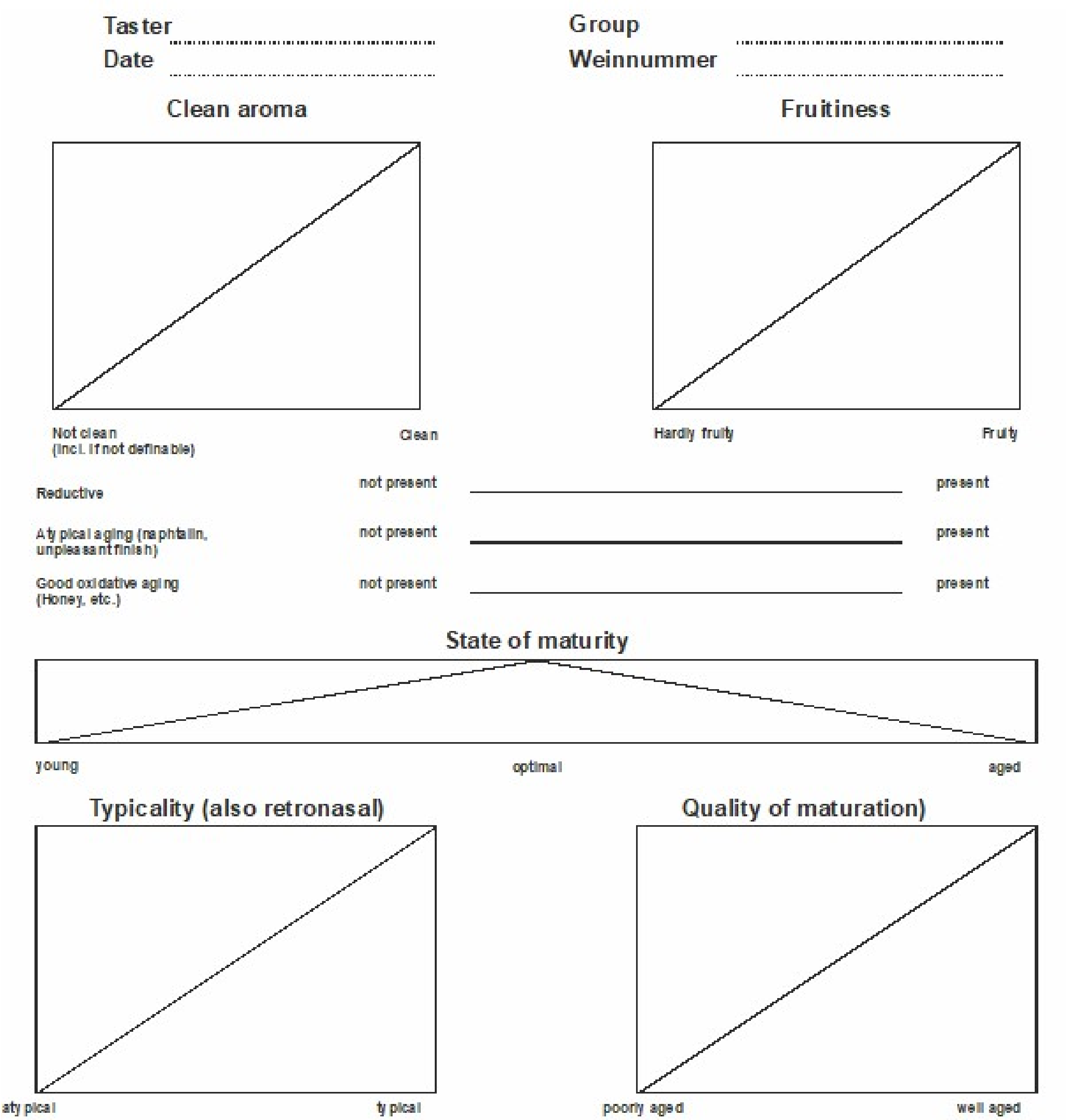

Fig. 1: Taster’s form for sensory description of wines under investigation.

switched to *Ruländer* and *Sauvignon* (Tab. 1).

The weather data was obtained from the weather station at the Laimburg site (46° 22' 56.834" N, 11° 17' 19.421" E). Because of the relative proximity of the four experimental sites, this data can be considered to be representative of the whole.

CANOPY MANIPULATION

In order to answer the investigation's question, after complete setting, the leaf area was managed as follows (Tab. 2). The "control" treatment (C) was headed as usual to a leaf area height of 120 cm; in the case of the "without lateral shoots" treatment (WLS), all of the shoots were removed manually; in the "low leaf area" (LL) the canopy was shortened to 50 cm below the height of the 'control'; in contrast, the vines subjected to "shoots twisted" treatment (ST) were never hedged – instead, they were horizontally twisted along the upper pair of wires. In order to maintain these treatments during the entire vegetation period, at the two vigorous growth sites, several corrections had to be carried out on the LL and ST treatments.

At the low vigour sites, on the other hand, only minor intercession was required. The removal of the lateral shoots did not necessitate any further intercession. The partitioning of the parcels was based on a randomised block design, with three repetitions of each variant, in each of the three blocks, each of which consisted of 24 vines.

ANALYSIS AND VINIFICATION PROCEDURE

The size of the leaf area was measured using the Carbonneau method [14]. Additional agronomical measurements included determining the degree of berry ripeness at several points during the ripening period by sampling and analysing the sugar content (°KMW), total acidity (g/l), pH value, yeast-utilisable nitrogen content (mg/l) (measured with FOSS®, *WineScan™*), and yield parameters (grape and berry weight), yield per unit area (kg/m^2), and weight of pruned wood (kg/m^2). In order to measure the effects of the leaf area on the potential fruit-bearing capacity / yield of the vines, the number of inflorescences / shoots was determined before blossoming. Further measurements regarding the health of the grapes and physiological disease like berry shrivel were carried out shortly before harvesting.

The grapes were harvested by hand at the technological harvest time and transported to the winery in crates, each with a capacity of 18 kg.

Approximately 50 kg of grapes were processed for each repetition without maceration time. The procedure was as follows. After removal of the destemming machine's spiked roller, the destemming machine (*CMA Lugana 1R*, with a capacity of 4-6 tonnes per hour) was used to crush but not destem the grapes. The crushed grapes, together with the stems, were filled into 70-litre pneumatic water-pressure presses and then pressed (10 min. 1 bar – failure – 10 min 2.0 bar – failure – 10 min 2.0 bar). Thereafter, they were filled into 34-litre glass balloons and treated with 30 mg/l potassium meta-bisulphite (E 224). The must was subjected to static settling for 20 hours at 4 °C. The clear supernatant was then drawn off and the lees removed. The must was then heated up to a temperature of 22 °C and, depending upon the given repetition of the maturation process, a sample of the must was removed in order to investigate it for must weight, pH, total acidity, and yeast-utilisable nitrogen. Dry selected yeast of the species *Saccharomyces cerevisiae* var. cerevisiae (different strains) was rehydrated according to the manufacturer's instructions and used to inoculate the must.

The alcoholic fermentation took place at a constant 20.5 °C via regulated room temperature.

The fermentation duration was individual, depending upon the variety, vintage, and site. The wine was drawn off upon cessation of fermentation and/or upon attaining a residual sugar content of < 4.0 g/l. The first racking was without aeration, with sulphite treatment (E 224) at 30 mg/l.

This was followed by short-term storage in the cold store unit at 4 °C for approx. 10 days and then another drawing-off at a temperature of between 14 and 18 °C. During storage of the wine, a concentration of free sulfureous acid of 25 mg/l was adjusted and monitored. The wine was then filled up in 0.5-litre glass bottles immediately after previous pre-, blank, and sterile filtration (0.45 µm).

The must and wine were analysed for the following substances:

Must weight (°KMW), total acidity in the must (g/l), pH in the must, by means of FT-IR on the basis of RESOLUTION OIV/OENO 390/2010 (measured with FOSS®, *WineScan™*, SO2 with the use of the calibration of the Laimburg Wine Lab), as well as yeast-utilisable nitrogen in the must (mg/l) (photometrically after derivatisation of the primary amino group with OPA/NAC, as specified by methods book 5.04, 04), alcohol in the wine, total acidity of the wine (g/l), pH of the wine, extract in the wine (g/l), sugar-free extract in the wine – calculated (total dry extract – red sugar + 1), and residual sugar in the wine (g/l). The concentrations of these substances were determined by means of FT-IR on the basis of RESOLUTION OIV/OENO 390/2010 (FOSS®, *WineScan™*, SO2 with the use of the calibration of the Laimburg Wine Lab).

Additionally, the tartaric acid in the wine (g/l) was measured (2009 and 2010 ion chromatographically in accordance with methods book 5.04, 23, 2011 with FT-IR according to OIV/OENO 390/2010 and 2012 to 2014 photometrically) and malic acid in the wine (g/l) (2009 and 2010 ion chromatographically in accordance with methods book 5.04, 23; 2011 with FT-IR according to OIV/OENO 390/2010 and 2012 to 2014 photometrically). These chemical analyses were carried out by the Wine Lab of the Laimburg Research Centre in accordance with the methods set forth in its internal methods book.

SENSORY ANALYSIS

A year after pressing, all of the wines were subjected to sensory analysis. The following discriminating criteria were employed:

- Clean aroma, not clean – clean
- Fruitiness, hardly fruity – fruity
- Reductive, not present – present
- Atypical ageing, not present – present
- Good oxidative ageing, not present – present
- State of maturity of the wine, young – optimal – old
- Typicality (also retronasally determined), atypical – typical
- Quality of maturation, poorly matured – well matured
- For the 2010 (Chardonnay, only) and 2011 vintages (both varieties), the following criterion was also applied:
- Wine body, thin – full-bodied
- Length, short (approx. 3-4 sec) – persistent (approx. 7-9 sec)
- Overall impression, poor – good.

In order to determine the sensory characteristics, a tasting profile defined by Weiß [15] (modified – not published) was employed (Fig. 1). To check the certainty of judgement of the individual panel members, the Kobler method [16] was utilised. In so doing, the control algorithms were calculated for all of the individual parameters. The tasting panel was composed of technicians, consultants, vinicultural specialists, and expert winery personnel.

To evaluate the collected data, the following programmes were used: Microsoft ® *Office Excel 2003* of ©Microsoft Corporation 1993-2001, for statistical evaluation IBM® *SPSS®* Statistics Version 20 Release 20.0.0 for variance analysis comparisons of averages (Oneway ANOVA) or multivariant variance analysis (Manova).

RESULTS

WEATHER CONDITIONS

Table 3 and Table 4 present the most important climatological values – the mean temperature and precipitation in the months of the vegetation period (April-October) – for the years under investigation. The data were obtained from the weather station at the Laimburg Research Centre, which is located close to the research vineyards planted with *Chardonnay* and *Gewürztraminer* (approx. 100-300 m away). The *Sauvignon* and *Ruländer* vineyards are about 2-3 km distant from the Laimburg site. Except for the year 2009, during the period under investigation, consistently high levels of precipitation were recorded. The mean temperatures from April to October indicate that in all of the years, average temperatures of more than 17 ℃, and in four of the six years even above 18 ℃, were achieved. Thus, for the cultivation of white wine varieties, these were very warm weather conditions.

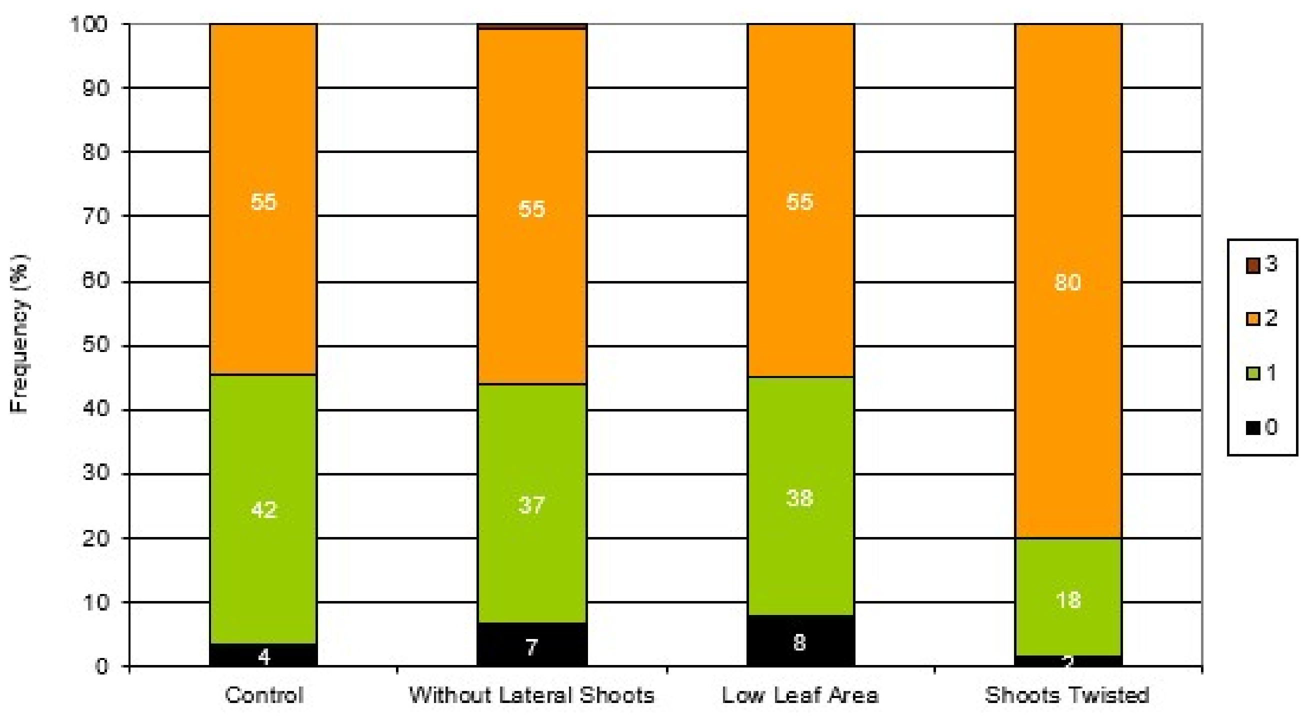

Fig. 2: Frequency of the number of inflorescences per shoot for Gewürztraminer in the third year under investigation.

SIZE OF LEAF AREA AND WEIGHT OF WOODY PARTS

The experimental treatments resulted in consistently pronounced effects on the size of the leaf area (potentially exposed foliar surface = SFEp) (Tab. 5, Tab. 6, Tab. 7, Tab. 8). In the case of the varieties of *Gewürztraminer* and *Chardonnay* in the "low leaf area" treatment (LL), in some cases only about half as much (average: 57%) exposed leaf area was observed as in the vines grown under usual conditions. In the case of *Sauvignon blanc* and *Ruländer* planted in the less fertile soils, even in the control, only a small leaf area was achieved; the difference between the control and the "low leaf area" was therefore not as large. The exposed leaf area in the "low leaf area" treatment amounted to 665 in comparison with the foliar surface of the control (100%).

This was because at the sites characterised by less vigorous growth, vegetative growth stopped early with the onset of the hot summer temperatures. In individual years and parcels, after the first topping of the shoots, there was hardly any more regrowth recorded in the control variant. In the case of the "without lateral shoots" treatment, too, consistently smaller exposed leaf surface area was observed than in the control. However, this difference was usually only statistically relevant with the more vigorous vineyards planted with *Chardonnay* and *Gewürztraminer*; for *Sauvignon* and *Ruländer*, this was the case just once.

The "shoots twisted" treatment was in most cases not significantly different from the control with respect to the exposed leaf surface area.

The weight of the woody parts displays a trend similar to that of the exposed leaf surface area (Tab. 5, Tab. 6, Tab. 7, Tab. 8). In the case of the "shoots twisted" treatment, the weight of woody parts was, in absolute terms, usually the highest; it was only about as high as in the control in just two cases. In the case of the "without lateral shoots" treatment, the weight of woody parts tended to always be less than in the control, but it was not possible to statistically discriminate this. In contrast, in the "low leaf area" treatment, the weight of woody parts was significantly lower than in the control in most cases.

YIELD, WEIGHT OF BERRIES AND GRAPES, FRUIT-BEARING CAPACITY

Because the yield of the vineyards was slightly regulated – in particular, the third grape on the shoot and grapes bunched too closely together were removed – relevant differences in yield were hardly observed. All in all, the targeted yield for *Ruländer* and in part also for *Sauvignon blanc* was not attained. Nevertheless, the evaluation of the fruit-bearing capacity (fruitfulness) – i.e., the number of inflorescences per shoot – yielded an unambiguous trend which was especially pronounced for *Gewürztraminer* and which is depicted in Figure 2. Surprisingly, in the treatments with reduced leaf surface area – i.e., in the "without lateral shoots" and "low leaf area" treatments – no pronounced effects on the number of inflorescences were observed. In contrast, the "shoots twisted" treatment consistently displayed a tendency to a higher production of inflorescences than the control. In the case of *Gewürztraminer*, this effect was statistically significant. As Figure 2 shows, in the third year of the investigation, in this variant, fewer shoots with only a single inflorescence, but significantly more shoots with two inflorescences were found.

In the case of the varieties of *Ruländer* and *Sauvignon blanc*, the weight of the berries and grape bunches displayed no significant differences (Tab. 7, Tab. 8). At the sites characterised by more vigorous growth and planted with *Chardonnay* and *Gewürztraminer*, some significant differences in the grape and berry weights of the individual treatments under investigation were observed; over the years under investigation, however, no discernible trend was observed (Tab. 5, Tab. 6).

SUGAR, ACIDITY, AND PH

The central objective of the investigation was to determine if a reduction of the leaf area can result in a delay in sugar storage and if ripe grapes with a low sugar content can be harvested. In the case of the *Gewürztraminer* and *Chardonnay* varieties, the "low leaf area" treatment tended to display a lower sugar content than the control; frequently, it was possible to secure this difference statistically (Tab.5, Tab. 6). At those sites with less vigorous growth that were planted with *Ruländer* and *Sauvignon blanc*, this was not the case. Rather, in these cases, the smaller leaf area resulted in only a very modest delay in ripening (Tab. 7, Tab. 8). The very limited delay in ripening due to reduced leaf area corresponds to an even more limited increase in total acidity which it was possible to secure statistically in only scattered instances (Tab. 5, Tab. 6, Tab. 7, Tab. 8). With respect to pH, in some cases the "low leaf area" treatment displayed significantly lower values relative to the control. However, in absolute terms, the differences between the variants were very modest.

YEAST ASSIMILABLE NITROGEN (YAN)

Table 5, Table 6, Table 7, and Table 8 depict the YAN values of the individual variants under investigation over the course of the period under observation. It can be seen that the values are always higher for *Chardonnay* and *Gewürztraminer* in the "low leaf area" treatment than in the control, and that it was in part possible to secure these differences statistically. Furthermore, it was possible to observe a distinctive higher amount of YAN in the „shoots twisted" treatment with statistical secure differences in one year for Chardonnay and all three years for Gewürztraminer. This is not the case with *Sauvignon blanc* and *Ruländer*. In the "low leaf area" treatment, too, the YAN content for *Chardonnay* and *Gewürztraminer* is usually slightly elevated compared with the control. However, this is not

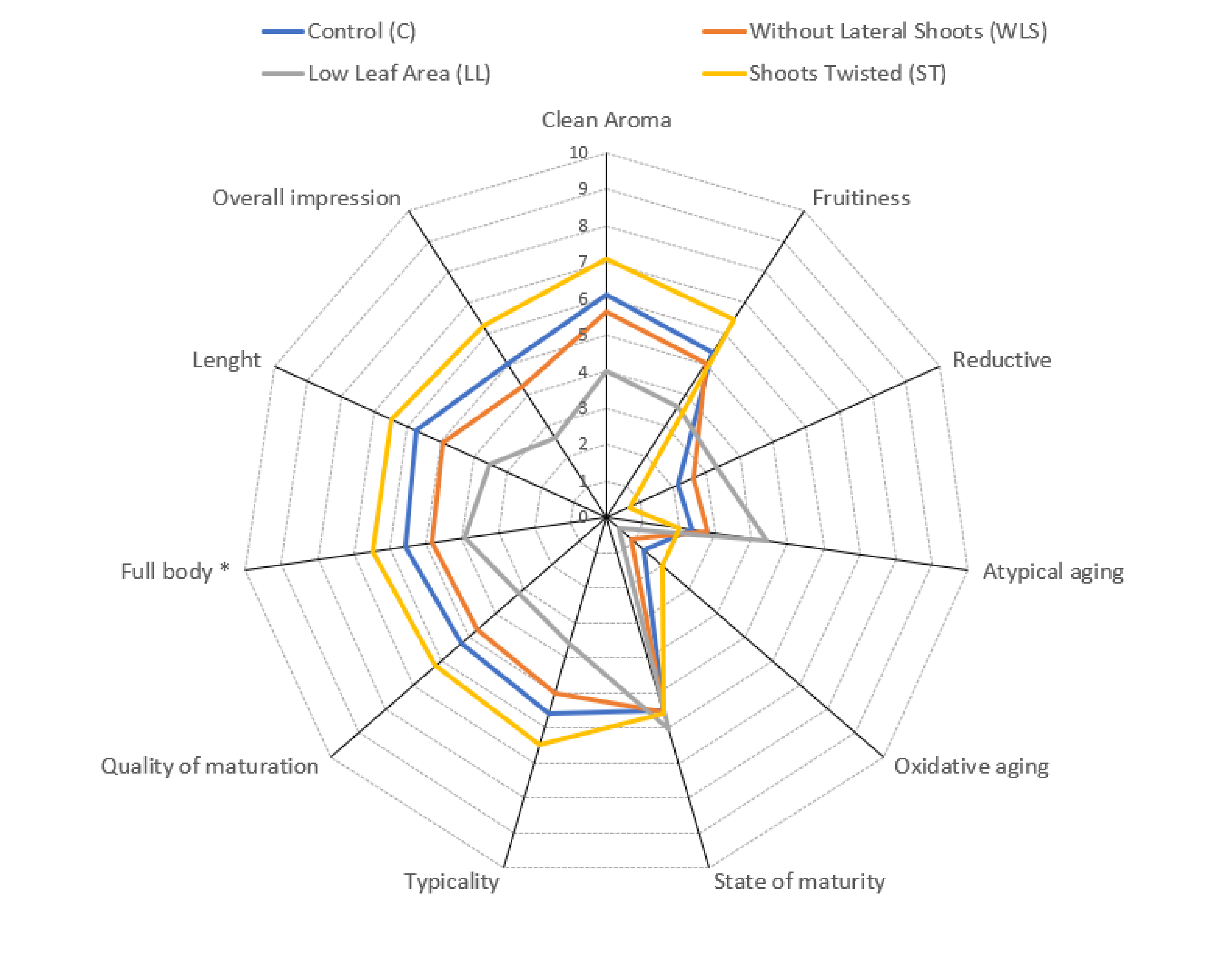

Fig. 3: Sensory description of Gewürztraminer for 2009 and 2011.

the case with *Ruländer* and *Sauvignon blanc*.

BERRY SHRIVEL

The findings for berry shrivel are not depicted. Increased Berry shrivel was observable in particular in the "low leaf area" treatment for *Chardonnay* and, even more distinctly, for *Gewürztraminer*.

WINE CONTENTS AND SENSORY CHARACTERISTICS

The effects of leaf area management on wine quality must be evaluated differently for each variety. Table 9 presents the findings for the most important wine constituents of the treatments under investigation. While for *Chardonnay* and *Gewürztraminer* on the average for the whole period under investigation leaf area management does elicit a certain effect, for *Sauvignon*, the influence of the measures was low and for *Ruländer*, no effects could be determined. For *Chardonnay*, the lower sugar content of the grapes from the "low leaf area" treatment naturally resulted in a lower alcohol content. This lower alcohol content had, in turn, the (statistically not significant) tendency to influence the wine body parameter. For *Gewürztraminer*, analytical differences with respect to macro constituents between the treatments were hardly observable during the period under investigation. Nevertheless, it was possible to observe quite perceptible sensory differences (Fig. 3). The "shoots twisted" treatment received the most positive evaluation with respect to almost all parameters, while the "low leaf area" treatment displayed distinctly negative sensory characteristics. In this context, the tendency towards atypical ageing is especially critical.

A low influence of "low leaf area" on the alcohol content was observable for *Sauvignon blanc* (- 0.63% by volume compared to the control). This had a statistically significant effect upon the wine body parameter ($p = 0.014$). The tartaric acid content in the "low leaf area" treatment was somewhat higher than in the control. For *Ruländer*, on average for the whole period under investigation, it was possible to achieve only a marginal analytical (Tab. 9) and sensory effect by means of the investigated leaf area treatments.

On average, over the entire period under investigation and with respect to all varieties, the "low leaf area" treatment harbours more risks than advantages, as shown by Figure 4, with a measurable sensory impact upon wine body and length and disadvantages with regard to overall impression.

DISCUSSION

The canopy manipulation treatments with strong leaf area reduction revealed only limited effects on grape ripening parameters, as well as the total acidity or pH of the must.

This could be explained in part by the low level of yield in the vineyards in which the measures were implemented. However, the level of yield in the investigation corresponds largely to that generally achieved in South Tyrolean wine production and thus also to that which can be expected in actual practice from these measures.

An additional reason for the limited effects of reduced leaf area on sugar accumulation that were observed – in contrast to the findings of Ollat and Gaudillere, Poni and Giachino, Stoll et al. and Parker et al. [5] [6] [7] [8] - can be attributed to the fact that the vineyards with the four varieties of white wine examined in this investigation are already located in a very warm climatic zone for the given varieties. Due to the reduction of the foliar surface, it was not possible to shift the ripening time far enough into the autumn that the final ripening would have taken place under distinctly cooler conditions. Consequently, the ripening in the investigation period proceeded at speed all the way up until harvest.

Another consideration against reducing the leaf area is the elevated risk for the incidence of berry shrivel due to the unfavourable leaf/fruit ratio characteristic of the "low leaf area" treatment [17] [18]. The quality of the wine derived from the "low leaf area" treatment was never judged to be superior to that of the control variant, but rather repeatedly inferior. Furthermore, a tendency towards the formation of atypical ageing notes was observed.

In the case of the "low leaf area" treatment, though no decrease in yield or in potential fertility was observed during the period under investigation, it was possible to observe an increase in potential fertility due to "shoot twisting." In many wine-producing regions today, the desired yields are no longer achieved, in part also because of the low formation of inflorescences. In these situations, "shoot twisting" should be a sensible measure to enhance vineyard yields.

The "shoot twisting" treatment displayed repeatedly higher YAN contents in the musts, especially in the vineyards with higher vegetation. This is probably attributable to the fact that, in this treatment, vegetative growth remained quiescent during the ripening phase, even given wet weather. In comparison to that, in the case of the shoot topped treatments, especially when sufficient soil moisture was present, in part very pronounced shoot growth was displayed. In those vineyards characterised by less vigorous growth, in the case of *Ruländer* and *Sauvignon blanc*, "shoot twisting" was not found to have any effects upon the YAN content. This method – now in practice to an extent in quality wine producing areas like in northern Italy and France – is thus quite reasonable. This method is to be recommended especially where vineyards have a certain degree of vigour, while vineyards which stop their vegetative growth early anyway would probably benefit less from this measure.

In this study, it was possible to observe the higher nitrogen contents found by Spring [19] in musts with reduced leaf area only in individual instances, as a slight tendency. But even when there was a tendency towards higher YAN contents in the "lower leaf area" treatment, this never led to a more positive evaluation of the wine quality.

The "without lateral shoots" treatment (WLS), where all of the lateral shoots were removed manually, behaved very similarly to the untreated control and showed no statistically significant deviations from it. This is most likely due to the moderate yield level of the experimental plants. The existing leaf mass was sufficient to supply the grapes well. Although this variant is likely to have advantages in terms of downy mildew limitation, as there is no longer any new leaf growth near the grape zone, no effects were recognisable in terms of delayed ripening. In summary, it can be concluded that in the case of the conditions prevailing during this investigation, reducing the leaf area does not represent a suitable measure for delaying ripening or improving wine quality.

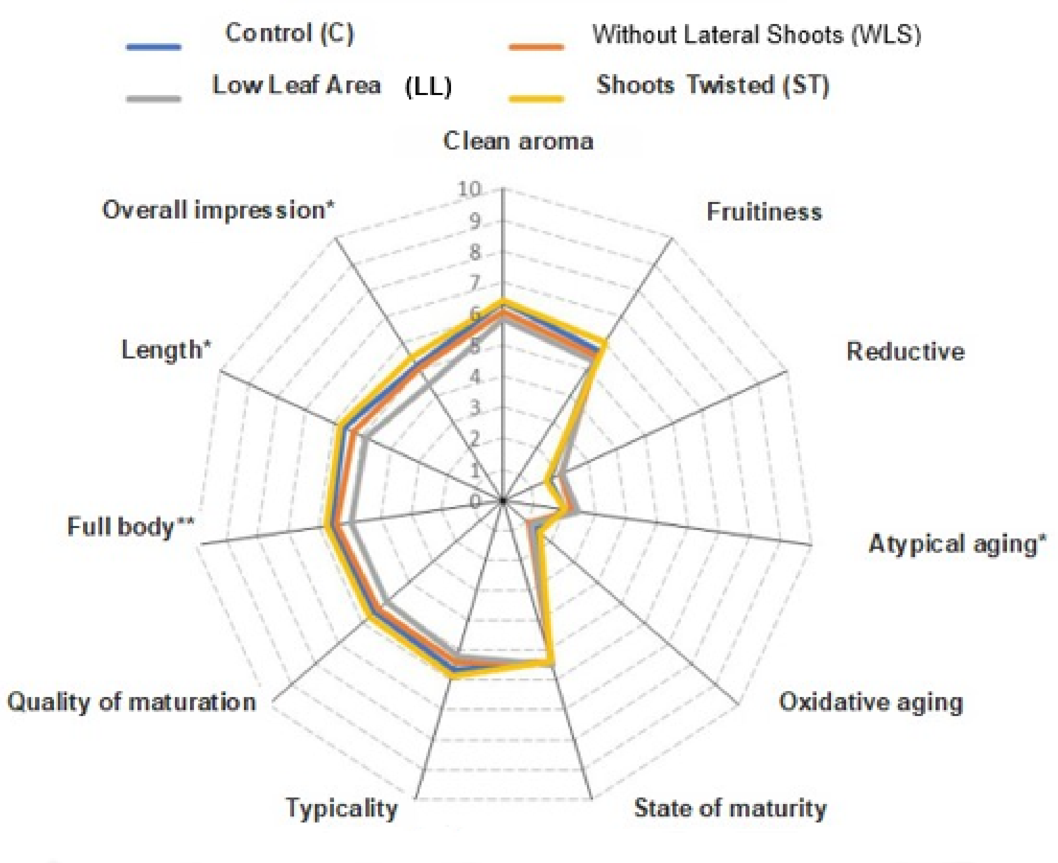

Fig. 4: Sensory description, mean values of all aged wines under investigation for the entire period and all varieties.

ZUSAMMENFASSUNG

Ziel dieser Arbeit war es, verschiedene Formen der Lauwandbehandlung und der Laubwandhöhe in Spalieranlagen auf die Einlagerung von Zucker und anderer Inhaltsstoffe der Beeren und Moste und auf die Weinqualität zu untersuchen. In zwei Anlagen mit starkem und zwei mit schwachem Wachstum wurden folgende Varianten geprüft: Die "Kontrolle" wurde gebietsüblich behandelt, in der Variante "ohne Geiztriebe" wurden diese fortlaufend entfernt, bei der "niederen Laubwand" wurde die Laubwand 50 cm tiefer gehalten im Vergleich zur Kontrolle und beim "Eindrehen der Triebe" wurden diese nie gegipfelt, sondern horizontal um das oberste Drahtpaar gewickelt. Die Variante "niedrige Laubwand" zeigte nur begrenzte Auswirkungen auf die Reifeparameter, dies vor allem bei geringem Wachstum der Anlagen. Die Weinqualität dieser Variante wurde nie besser aber mehrmals schlechter als die der Kontrolle bewertet. Weiters wurde in der Variante "niedrige Laubwand" eine Tendenz zu atypischen Alterungsnoten der Weine festgestellt sowie teilweise deutlich erhöhtes Auftreten von Traubenwelke. Das "Eindrehen der Triebe" führte zu höheren Gehalten an hefeverwertbarem Stickstoff vor allem bei kräftigem Wachstum der Rebanlagen und verbesserte die Fruchtbarkeit der Reben. Unter den gegebenen Bedingungen stellt die Reduzierung der Laubwand keine geeignete Maßnahme dar, um die Reife zu verzögern und die Weinqualität zu verbessern.

RIASSUNTO

L’obiettivo di questo lavoro è stato di indagare, in sistemi di allevamento a spalliera, l’effetto sull’accumulo di zuccheri ed altri costituenti nelle uve e sulla qualità dei vini, da parte di diverse forme di gestione della parete fogliare. Per la prova sono stati individuati quattro siti, due siti a vigoria elevata e altri due a vigoria ridotta, con allestite quattro diverse tesi. Il "Testimone" è stato trattato in maniera usuale per la zona, nella variante "senza polloni" questi sono stati eliminati continuamente, nella tesi "parete fogliare ridotta" la parete fogliare è stata mantenuta 50 cm più bassa rispetto al testimone e nella tesi "tralci arrotolati" questi non sono stati cimati, bensì arrotolati orizzontalmente attorno ai fili superiori della parete fogliare. La variante "parete fogliare ridotta" ha mostrato solo effetti limitati sui parametri di maturità, soprattutto nei siti a vigoria ridotta. La qualità di vino di questa tesi non è mai stata giudicata superiore, ma più volte è stata meno apprezzata rispetto al testimone. Inoltre, questa tesi ha rivelato una tendenza a note da invecchiamento atipico dei vini ed in parte è stato osservato una presenza elevata di avvizzimento del grappolo. La tesi dei "tralci arrotolati" invece ha evidenziato livelli di azoto prontamente assimilabile più alti rispetto al testimone soprattutto nei siti ad elevato vigore e ha migliorato la fertilità delle piante. Nelle condizioni date, la riduzione dell’altezza della parete fogliare non è una misura idonea per ritardare la maturazione e migliorare la qualità dei vini.

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ANNEX: TABLES

Tab. 1: Overview of varieties and sites

Chardonnay	Gewürztraminer
Site: Laimburg Hausanger	Site: Laimburg Stadlhof
Clone 584, rootstock SO4	Clone LB 14, rootstock SO4
Year of planting: 1995	Year of planting: 2006
Planting distance: 2 x 0,8 m	Planting distance: 2 x 0,8 m
Training system: simple Guyot	Training system: simple Guyot
Ruländer (Pinot gris)	**Sauvignon blanc**
Site: Kaltern Mazzon	Site: Kaltern Plantaditsch
Clone, rootstock SO4	Clone LB, rootstock SO4
Year of planting: 1995	Year of planting: 2008
Planting distance: 2 x 0,8 m	Planting distance: 2 x 0,8 m
Training system: simple Guyot	Training system: simple Guyot

Tab. 2: Overview of the tested treatments.

Variant	Measure
Control (C)	Headed at 120 cm shoot length as usual
Without lateral shoots (WLS)	All lateral shoots removed by hand
Low leaf area (LL)	Leaf area shortened to 50 cm below the height of the ‘control’
Shoots twisted (ST)	No decapitation; rather, shoots are twisted into upper pair of trellis wires

Tab. 3: Mean monthly temperatures and mean temperatures during the vegetative period in the years under investigation.

	April (°C)	May (°C)	June (°C)	July (°C)	August (°C)	September (°C)	October (°C)	Mean temperature during vegetation period (°C)
2009	13.5	19.4	20.8	22.2	23.3	18.2	11.7	18.4
2010	13.1	16.6	21.3	24.7	21.3	16.3	9.9	17.6
2011	15.1	18.4	20.1	21.2	22.8	19.3	10.7	18.2
2012	11.9	17.4	21.9	22.5	23.4	17.6	12.0	18.1
2013	13.7	15.4	20.1	23.7	22.5	17.9	13.1	18.1
2014	13.8	16.6	21.0	21.2	19.7	18.0	13.8	17.7

Tab. 4: Monthly precipitation during the vegetative period in the years under investigation.

	April (mm)	May (mm)	June (mm)	July (mm)	August (mm)	September (mm)	October (mm)	Precipitation during vegetation period (mm)
2009	64.3	6.6	50.6	92.0	69.4	52.1	31.1	366.1
2010	45.5	10.8	63.4	30.6	173.4	122.3	109.7	646.7
2011	28.9	63.9	96.2	84.6	70.2	141.0	101.7	586.5
2012	125.3	70.0	100.2	96.4	74.3	119.0	92.5	677.7
2013	51.5	158.1	82.3	73.9	81.6	52.8	190.3	690.5
2014	49.9	22.7	90.9	132.7	92.2	43.5	72.7	504.6

Tab. 5: Analytical values for must at harvest, yields, weight of woody parts, and leaf area for the individual variants in the three years under investigation for *Chardonnay.*

Year	Variant	Grape weight		Yield		Berry weight		Sugar content		Total acidity		pH value		HVS		Pruning weight		SFEp	
		g		kg/m^2		g		°Babo		g/l				mg/l		kg/m^2		m^2	
2009	C	175.1	a	1.19		1.91		19.0	b	7.40	ab	3.5	b	243.3		0.2406	b	1.24	b
2009	WLS	185.3	ab	1.14		1.82		18.8	ab	7.10	a	3.47	ab	258.3		0.2441	b	0.77	a
2009	LL	210.1	b	1.17		1.88		18.4	a	7.60	ab	3.42	ab	267.7		0.1810	a	0.87	a
2009	ST	188.4	ab	1.20		1.92		18.8	ab	7.80	b	3.43	ab	285.0		0.2813	b	1.51	b
p - value		0.045		n.s.		n.s.		0.021		0.015		0.018		n.s.		0.004		0.001	
2010	C	144.3	b	1.06	b	1.97	b	18.6	b	9.60	ab	3.39		199.7	a	0.4125	b	1.36	b
2010	WLS	136.1	ab	1.04	b	1.92	ab	18.4	b	9.40	ab	3.38		211.0	a	0.3898	b	1.31	b
2010	LL	134.0	ab	0.99	ab	1.83	a	17.4	a	9.20	a	3.39		285.7	b	0.2676	a	0.84	a
2010	ST	125.7	a	0.82	a	1.87	a	18.7	b	9.90	b	3.41		276.3	b	0.5159	b	1.67	c
p - value		0.05		0.03		0.007		0.000		0.04		n.s.		0.002		0.000		0.001	
2011	C	170.2	b	1.13		1.95		18.2	b	9.30	b	3.30	a	257.0	a	0.4321	bc	1.36	c
2011	WLS	156.7	ab	1.09		1.86		18.0	ab	8.60	a	3.32	ab	266.0	a	0.3848	b	0.87	b
2011	LL	152.0	a	1.05		1.87		17.6	a	8.90	a	3.30	a	276.0	a	0.2195	a	0.60	a
2011	ST	185.6	c	1.22		1.91		17.7	a	9.50	b	3.35	b	370.7	b	0.5441	c	1.67	d
p - value		0.000		n.s.		n.s.		0.006		0.000		0.003		0.008		0.000		0.000	

Tab. 6: Analytical values for must at harvest, yields, weight of woody parts, and leaf area for the individual variants in the three years under investigation for *Gewürztraminer.*

Year	Variant	Grape weight		Yield		Berry weight		Sugar content		Total acidity		pH value		HVS		Pruning weight		SFEp	
		g		kg/m^2		g		°Babo		g/l				mg/l		kg/m^2		m^2	
2009	C	172.3		0.89		1.824		20.5		4.4		3.82		191.7		0.319	a	1.59	b
2009	WLS	181.7		1.07		1.735		20.4		4.9		3.71		206.7		0.356	ab	1.23	a
2009	LL	170.1		1.06		1.912		19.9		4.7		3.72		192.3		0.266	a	0.95	a
2009	ST	179.1		1.11		1.867		19.8		4.5		3.84		247.3		0.443	b	1.50	b
p - value		n.s.		n.s.		n.s.		n.s.		n.s.		n.s.		n.s.		0.000		0.000	
2010	C	121.7		0.70		1.553		20.2		4.6	ab	3.73	ab	160.3		0.360	b	1.54	c
2010	WLS	122.0		0.74		1.483		20.1		4.9	ab	3.68	ab	180.3		0.405	bc	1.10	b
2010	LL	127.2		0.74		1.427		19.8		5.1	b	3.59	a	210.7		0.194	a	0.80	a
2010	ST	131.9		0.84		1.547		20.1		4.6	a	3.82	b	265.0		0.499	c	1.60	c
p - value		n.s.		n.s.		n.s.		n.s.		0.047		0.034		n.s.		0.000		0.000	
2011	C	143.5	ab	0.82	ab	1.723	b	20.3		5.2	ab	3.69		228.3		0.368	b	1.26	c
2011	WLS	128.4	a	0.73	a	1.620	ab	20.0		5.7	b	3.65		267.7		0.378	b	0.90	b
2011	LL	156.6	b	0.87	ab	1.562	a	19.6		5.8	b	3.57		249.3		0.205	a	0.69	a
2011	ST	149.2	ab	0.94	b	1.560	a	20.0		5.1	a	3.82		241.7		0.561	c	1.61	d
p - value		0.024		0.05		0.11		n.s.		0.041		n.s.		n.s.		0.000		0.000	

Tab. 7: Analytical values for must at harvest, yields, weight of woody parts, and leaf area for the individual variants in the three years under investigation for *Ruländer.*

Year	Variant	Grape weight	Yield		Berry weight	Sugar content		Total acidity	pH value	HVS	Pruning weight		SFEp	
		g	kg/m^2		g	°Babo		g/l		mg/l	kg/m^2		m^2	
2012	C	92.4	0.61		1.332	19.6		6.8	3.24	101.3	0.199	bc	1.06	
2012	WLS	94.8	0.70		1.288	19.9		6.5	3.27	105.8	0.184	bc	0.86	
2012	LL	98.0	0.67		1.336	19.5		6.9	3.24	110.3	0.130	a	0.81	
2012	ST	86.0	0.58		1.335	19.8		6.5	3.25	97.0	0.236	c	1.5	
p - value		n.s.	n.s.		n.s.	n.s.		n.s.	n.s.	n.s.	0.000		n.s.	
2013	C	97.7	0.62		1.100	19.2	a	9.0	3.05	95.4	0.222	ab	1.31	b
2013	WLS	99.0	0.64		1.080	18.9	a	8.7	3.04	86.7	0.196	ab	1.07	ab
2013	LL	98.9	0.57		1.009	18.9	a	8.6	3.06	76.9	0.125	a	0.82	a
2013	ST	91.8	0.58		1.101	19.6	b	9.0	3.06	102.3	0.256	c	1.35	b
p - value		n.s.	n.s.		n.s.	0.033		n.s.	n.s.	n.s.	0.000		0.005	
2014	C	110.7	0.72	b	1.235	18.8		8.8	3.08	102.3	0.174	b	1.15	b
2014	WLS	103.1	0.71	b	1.105	19.2		8.4	3.08	83.8	0.137	b	0.82	a
2014	LL	101.8	0.56	a	1.136	18.8		8.5	3.09	89.5	0.089	a	0.75	a
2014	ST	103.5	0.68	ab	1.160	18.9		8.7	3.09	93.5	0.176	b	1.13	b
p - value		n.s.	0.022		n.s.	n.s.		n.s.	n.s.	n.s.	0.000		0.005	

Tab. 8: Analytical values for must at harvest, yields, weight of woody parts, and leaf area for the individual variants in the three years under investigation for *Sauvignon blanc.*

Year	Variant	Grape weight	Yield	Berry weight	Sugar content		Total acidity	pH value		HVS		Pruning weight		SFEp	
		g	kg/m^2	g	°Babo		g/l			mg/l		kg/m^2		m^2	
2012	C	109.0	0.85	1.240	18.0		6.5	3.12	b	114.8		0.195		0.91	
2012	WLS	108.5	0.77	1.241	17.7		6.5	3.12	b	123.0		0.195		0.54	
2012	LL	97.7	0.67	1.200	18.0		7.2	3.04	a	96.3		0.190		0.57	
2012	ST	103.4	0.77	1.262	18.4		6.8	3.10	b	114.0		0.194		1.01	
p - value		n.s.	n.s.	n.s.	n.s.		n.s.	0.032		n.s.		n.s.		n.s.	
2013	C	121.6	0.60	1.304	18.9		7.7	3.14		123.6		0.214	b	1.10	
2013	WLS	103.7	0.58	1.221	18.8		7.8	3.13		130.3		0.232	b	0.80	
2013	LL	115.6	0.62	1.276	18.1		7.6	3.15		135.9		0.149	a	0.72	
2013	ST	106.1	0.59	1.264	19.0		7.6	3.16		137.3		0.240	b	1.19	
p - value		n.s.	n.s.	n.s.	n.s.		n.s.	n.s.		n.s.		0.000		n.s.	
2014	C	160.3	0.73	1.584	19.4	b	9.6	3.09		173.0	ab	0.265	b	1.36	b
2014	WLS	143.6	0.64	1.563	19.2	b	9.4	3.09		147.0	a	0.210	ab	1.12	ab
2014	LL	155.2	0.70	1.430	18.5	a	9.4	3.12		194.8	b	0.148	a	0.89	a
2014	ST	145.1	0.67	1.587	19.5	b	9.7	3.12		197.8	b	0.260	b	1.37	b
p - value		n.s.	n.s.	n.s.	0.000		n.s.	n.s.		0.003		0.000		0.002	

Tab. 9: Wine constituents, aggregated by variety; average values during wine ageing.

Variety	Variant	Alcohol		Total acidity		Tartaric acid		Malic acid		pH value		Total polyphenol according to Folin	
		% vol		g/l		g/l		g/l				mg/l	
mean for 2009-2011													
Chardonnay	control (C)	13.47	b	5.53	b	1.83		3.35	a	3.74	a	215	a
Chardonnay	without lateral shoots (WLS)	13.14	b	5.14	a	1.77		3.26	a	3.79	b	231	b
Chardonnay	low leaf area (LL)	12.64	a	5.48	b	1.86		3.47	ab	3.77	ab	236	b
Chardonnay	shoot twisting (ST)	13.08	b	5.6	b	1.71		3.72	b	3.80	b	219	a
	p-value	0.01		0.01		n.s.		0.02		0.01		0.007	
mean for 2009-2011													
Gewürztraminer	control (C)	14.99		3.17		1.42		1.4		3.94	bc	205	b
Gewürztraminer	without lateral shoots (WLS)	14.77		3.37		1.54		1.41		3.85	ab	202	b
Gewürztraminer	low leaf area (LL)	14.45		3.57		1.47		1.43		3.77	a	185	a
Gewürztraminer	shoot twisting (ST)	14.44		2.93		1.52		1.64		4.07	c	217	b
	p-value	n.s.		n.s.		n.s.		n.s.		0.01		0.007	
mean for 2012-2014													
Ruländer	control (C)	14.61		6.94		2.77		1.55		3.24		249	
Ruländer	without lateral shoots (WLS)	14.46		6.78		2.49		1.51		3.23		449	
Ruländer	low leaf area (LL)	14.33		6.89		2.63		1.53		3.24		248	
Ruländer	shoot twisting (ST)	14.61		6.86		2.58		1.54		3.26		254	
	p-value	n.s.		n.s.		n.s.		n.s.		n.s.		n.s.	
mean for 2012-2014													
Sauvignon B.	control (C)	14.24		6.38		2.82	a	1.58		3.24		222	
Sauvignon B.	without lateral shoots (WLS)	14.03		6.44		2.99	ab	1.52		3.23		230	
Sauvignon B.	low leaf area (LL)	13.61		6.73		3.15	b	1.59		3.18		216	
Sauvignon B.	shoot twisting (ST)	14.29		3.36		2.93	ab	1.49		3.25		228	
	p-value	n.s.		n.s.		0.04		n.s.		n.s.		n.s.	