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Ergonomic Evaluation of California Winegrape Trellis Systems

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Abstract. The winegrape industry suffers from high incidence rates of work related musculoskeletal disorders (MSDs). Pruning of dormant vines requires long periods of highly repetitive and physically demanding work that increases risk for MSDs. The purpose of this study is to quantify risk factors associated with the development of musculoskeletal injuries to the wrist and lower back while pruning five commonly used winegrape trellis systems. Eleven subjects (10 male, 1 female) participated in this study. Subjects performed a simulated pruning task as wrist and trunk postures and psychophysical data were gathered. The results showed significant differences among the trellis systems. Compared to the other systems, the vertical shoot positioned (VSP) was determined to be most optimal in terms of decreasing relative MSD risk. These results will assist vineyards in selecting suitable trellis systems that may improve worker health.

Keywords. Ergonomics, vineyards, winegrape, musculoskeletal disorders.

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Introduction

The agriculture industry has been recognized as one of the Nation's most hazardous industries (Meyers, 1999). AgSafe (AgSafe, 1992) reported that California's agriculture industry suffered from an excessive number of work related injuries, primarily in the form of cumulative trauma disorders (CTDs). The most commonly reported injuries within the agricultural industry were musculoskeletal disorders (MSDs) (Villarejo, 1999).

In the winegrape industry alone, a work-related MSD incidence rate of 80 per 1000 workers (Meyers, 2000) was reported. The most commonly recorded injuries were attributed to MSDs of the lower back and the upper extremities. These were due to the highly forceful and repetitive hand intensive movements combined with frequent stooped postures common to the majority of the labor-intensive tasks. Grape vineyards utilized for the production of wine are prominent and extensive in Northern California with more than 400,000 acres situated in the Sonoma and Napa valleys. In 1997, the production of winegrapes within California was estimated to account for over 95% of grapes crushed within the US. Approximately half of the existing commercial wineries in the US are located in California, employing more than 31,000 workers per year (Meyers, 1999).

The pruning of dormant vines requires considerable effort and time. Typically this involves six-to-twelve week periods every year between the months of December and March. The pruning operation, among the various procedures involved in the production of wine, is one of the most expensive and labor consuming, and is exceeded in both respects only by the harvest process (Tassie, 1992). Field visits have shown on average that typical pruning work shifts are 8 hours with approximately 2330 cuts/hour. In 2001, field visits were made to vineyards throughout the Napa and Sonoma regions to observe and obtain information concerning the processes involved with the pruning operation. The results of this preliminary research have identified several high-risk factors such as sustained awkward body postures (i.e. flexion of the torso, flexion of the knee and deviation of the neck from the neutral position) and the highly repetitive and forceful hand and arm/shoulder motions.

The pilot study also revealed that five trellis systems constituted the majority of hand-pruned trellises used throughout Northern California. In general, the design characteristics of these systems vary significantly (Dokoozlian, 2000). These differences are expected to result in differences in workers exposure to MSD risk. Finding a trellis system that minimizes MSD risk factors would be beneficial in reducing the prevalence of MSDs in the winegrape industry. Therefore, the objective of this study is to quantitatively evaluate five commonly used trellis systems throughout the Northern California winegrape vineyard industry. This evaluation will be based on the relative risks of developing MSDs to the wrist and the lower back while pruning. It is hoped that the results of this study will assist vineyard proprietors to select an optimal trellis system with regards to minimizing MSD risk exposure to the employee.

Safety Emphasis

This paper focuses on improving the health of the vineyard worker. Emphasis was placed on selecting a trellis system that minimizes relative MSD risk while pruning.

Methods

Subjects

Eleven healthy subjects (10 males and 1 female) each with pruning experience participated in this study. Pruning experience across subjects ranged from 5-15 years. The mean age was 39 years (10.3 std. dev.), and mean stature was 169.5 cm (10.1 std. dev.). All subjects were screened with regard to any current or previous MSD of the back and upper extremities.

Apparatus

Five simulation trellis systems were constructed for this study: Lyre, Scott Henry, Smart Dyson, VSP 4x4 and VSP. The cutting heights were based on average vineyard standards and are as follows: 61.0 cm-VSP 4x4, 86.4 cm-Scott Henry, 99.1 cm-Smart Dyson, 106.7 cm-VSP and 122 cm-Lyre. The row length for all trellis systems was approximately 9.1 m.

The Motion Analysis System (MAS) (Greenleaf Medical Systems, Palo Alto, CA) is an electrogoniometric device used to capture kinematic data of the wrist in the flexion/extension and radial/ulnar planes. The MAS consists of two gloves (one per hand) with cutouts for the digits and compartments for the transducers. The MAS is equipped with a portable data logger and a SRAM card capable of capturing continuous data. Data collection frequency was 20 Hz.

The Lumbar Motion Monitor (LMM) (Chattecx Corp., Hixon, TN) is an electrogoniometric device used to track the motion of the trunk in the three principal anatomical planes (sagittal, transverse and coronal). A wireless transmitter sends continuous data from the LMM to a laptop computer enabling the researcher to collect data without hindering the performance of the subject. Data collection frequency was 60 Hz. Figure 1 shows a subject equipped with the LMM and MAS while performing a pruning trial on one of the simulated trellis systems.



Figure 1. A subject performs a pruning trial on a simulation trellis.

Experimental Design

The study was a one-way within-subject design with five levels (trellis type). Several dependent variables were collected in this study. However, this paper focused on mean wrist (flexion/extension) and trunk (sagittal) postures, percent of time spent in specified ranges of the wrist (flexion/extension) and trunk (sagittal plane), and subjective ranking of the trellis systems. The pruning sequence for the trellis systems was randomly presented across all subjects.

Experimental Procedure

Each subject agreed to participate in the study and signed an informed consent form. Data were collected on two subjects per day.

Baseline readings from the LMM and MAS systems were collected for each subject prior to data collection. Each subject was instructed to prune half of each row per trellis system and to perform the pruning task as they would normally. For the LMM, each subject was instructed to stand in an upright posture prior to and after the pruning of all systems to obtain neutral postural data for normalization purposes.

A five-point subjective ranking instrument was verbally administered at the completion of the last trellis system to capture subject's trellis preference. The subjects were asked to rank the trellis systems in terms of difficulty pertaining to bodily discomfort from least (rank = 1) to most difficult (rank = 5). The subjects were asked to respond assuming a typical eight-hour work-shift.

Data Analysis

Overall averages for the postural data in the flexion/extension and radial/ulnar planes were determined for both wrists. In addition, flexion, extension, radial and ulnar postures were analyzed separately. This was done due to the positive and negative values (i.e., extension and flexion) that may nullify the true postural representation. Similarly, overall (i.e., sagittal flexion/extension) and posture specific (i.e., sagittal extension) trunk averages were obtained. Analyses of variances (ANOVAs) were performed to determine statistical differences in wrist and trunk postures among the trellis systems.

Frequency distributions centered on ranges of motion for the wrists and trunk in each respective plane of motion were created. The percent of time spent within a specified range was established for each principal plane of motion. The posture specific ranges of the wrist were based on the MAS software. The ranges for the wrist flexion/extension angle (θ) are defined as follows:

$$1 = \theta \leq -15^\circ \quad 2 = -15^\circ < \theta < 15^\circ \quad 3 = 15^\circ \leq \theta < 30^\circ \quad 4 = 30^\circ \leq \theta$$

The posture specific ranges of the trunk were based on parameters established by Fathallah et al., (1998). The ranges for the movement of the trunk in the sagittal plane angle (θ) are defined as follows:

$$1 = \theta < 0^\circ \quad 2 = 0^\circ \leq \theta < 15^\circ \quad 3 = 15^\circ \leq \theta < 30^\circ \quad 4 = 30^\circ \leq \theta$$

An average percent of time was obtained by taking the ratio of the number of data points that fell within the specified range and the overall number of collected data points per subject. The obtained ratios were collapsed across all subjects resulting in average values per trellis system. ANOVAs were performed to determine statistical differences among the trellis systems.

Coefficients of variation (R^2) were determined to quantify the strength of association between the postural data of the trunk and wrist. R^2 s were also determined for the relationship between the trunk and wrist postures and the cutting heights of each trellis system.

A non-parametric analysis was performed on the subjective ranking of the trellis systems. A Friedman ANOVA was conducted with the rankings from nine out of the eleven subjects. The responses from two subjects were not complete.

Results and Discussion

The ANOVA results for the overall and posture specific averages for both wrists are shown in Table 1. The overall conditions resulted in significant differences among the five trellis systems. Differences were noticed in the flexion/extension and radial/ulnar planes for the left wrist and in the flexion/extension plane for the right wrist. Significance was also noticed for the left extension and left ulnar posture specific conditions. The inconsistent DF error values associated with several of the independent ANOVAs were due to the elimination of subjects as a result of technical errors in the data collection process.

Table 1. ANOVA table for wrist postures (right and left).

Overall	DF Effect	MS Effect	DF Error	MS Error	F	p-level
Left Flexion/Extension	4	130.797	40	59.496	2.198	0.087*
Left Radial/Ulnar	4	205.324	36	61.275	3.351	0.020**
Right Flexion/Extension	4	136.589	36	59.296	2.304	0.077*
Right Radial/Ulnar	4	22.919	40	19.634	1.167	0.340
Posture Specific						
Left Flexion	4	23.285	8	17.784	1.309	0.345
Left Extension	4	160.382	36	37.013	4.333	0.006**
Left Ulnar	4	227.691	20	91.267	2.495	0.076*
Left Radial	4	69.107	16	30.326	2.279	0.106
Right Flexion	4	23.321	32	17.788	1.311	0.287
Right Extension	4	35.589	36	25.981	1.370	0.264
Right Ulnar	4	4.058	20	4.775	0.850	0.510
Right Radial	4	21.088	24	14.007	1.506	0.232

* Significant at $p < 0.1$

** Significant at $p < 0.05$

Of particular interest was the overall and posture specific averages for the left wrist. Figures 2 and 3 show the overall average of the left wrist in the flexion/extension planes and the posture specific average for the extension of the left wrist respectively. LSD comparisons were completed for the left flexion/extension conditions and Newman-Keuls comparisons were completed at the $p < 0.05$ -level for the left extension condition. Dissimilar letters as shown on each figure indicate significant differences between the trellis systems.

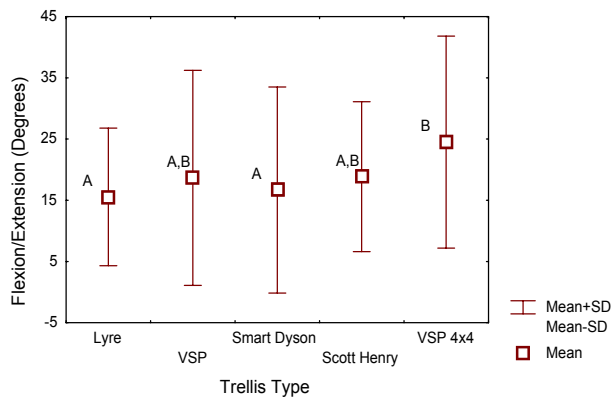


Figure 2. Average flexion/extension of left wrist.

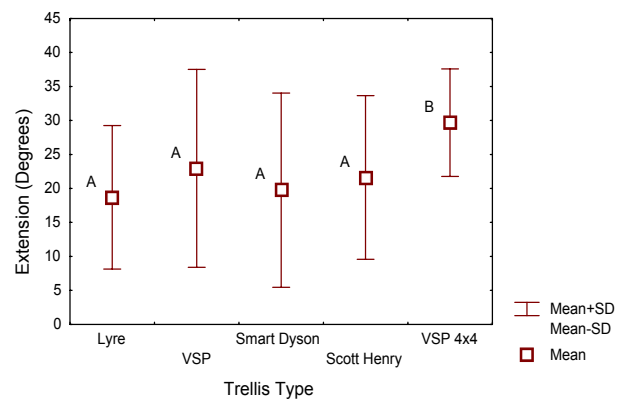


Figure 3. Average extension of left wrist.

The magnitude of wrist extension for the VSP 4x4 was significantly different compared with the other systems as shown in Figures 2 and 3. The mean posture of the left wrist in the flexion/extension plane for the VSP 4x4 system was approximately 24.5°. A similar result was obtained for the posture specific condition with an average of 29.7°. The larger extension values may be due to the forced posture of the wrist to accommodate the relatively low cutting height. The VSP 4x4 tends to position the subject into squat/stoop postures. These extreme postures seem to affect the left (non-cutting) hand, which is used to support and remove the branches that will be and have been cut.

Table 2 shows the ANOVA results for the overall and posture specific trunk averages. The overall and posture specific conditions resulted in significant differences among the five trellis systems. Differences were noticed in the overall coronal and sagittal planes and in the coronal right and left, sagittal flexion and transverse right conditions. An analysis on the sagittal extension condition was not performed due to the lack of subjects that experienced trunk extension.

Table 2. ANOVA table for trunk postures.

Overall	DF Effect	MS Effect	DF Error	MS Error	F	p-level
Coronal	4	103.400	40	10.759	9.611	0.000**
Sagittal	4	3505.871	40	26.821	130.713	0.000**
Transverse	4	0.677	40	5.419	0.125	0.973
Posture Specific						
Coronal Right	4	11.816	40	4.734	2.496	0.058*
Coronal Left	4	43.957	40	4.339	10.130	0.000**
Sagittal Flexion	4	2756.503	40	39.602	69.605	0.000**
Transverse Right	4	3.589	36	1.424	2.520	0.058*
Transverse Left	4	2.759	40	2.508	1.100	0.370

* Significant at $p < 0.1$

** Significant at $p < 0.01$

The differences observed for the overall trunk position in the coronal plane were statistically significant. However, the average range of motion within the coronal plane across all trellis

systems was 8° (-5° left and 3° right). Significant differences were also noticed for the coronal right and left conditions. Although significance was achieved, the average range of motion within the coronal right and left conditions across all trellis systems was approximately 4° and 5°, respectively. Therefore, these differences may be due in part to positioning of the trunk based on individual preference. Similarly, significance was achieved for the transverse right condition. However, this difference can also be attributed to variation in individual preference. The resulting average range of motion was approximately 2°.

Due to the assumption that the differences observed for the coronal and transverse conditions were the result of individual postural adjustments, attention will be primarily focused on the sagittal flexion and extension conditions.

Significant differences among trellis systems were observed for the overall trunk posture in the sagittal plane and the sagittal flexion of the trunk as shown in Figures 4 and 5. As expected, there was a direct relationship between trellis height and trunk flexion angles.

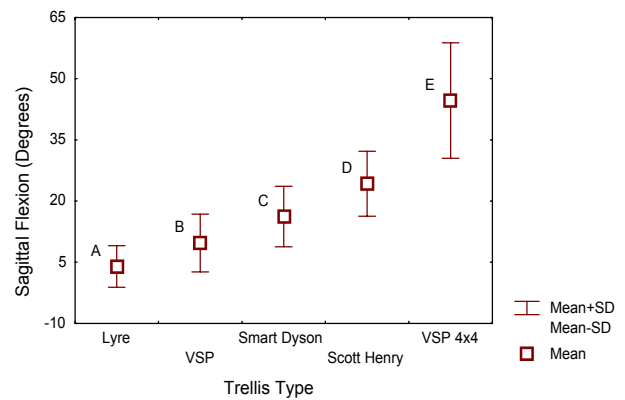
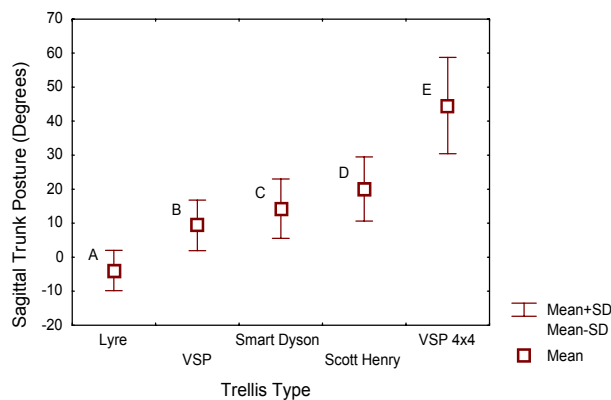


Figure 4. Mean trunk posture (sagittal plane).

Figure 5. Mean trunk posture (sagittal flexion).

The Lyre (highest pruning level) was the only system that resulted in slight extension of the trunk with an average of approximately 4°. Subjects positioned themselves to cut with a constantly elevated shoulder posture. The VSP system resulted in the lowest trunk flexion angles with an average of 9.4° compared with the other systems. This indicates that this system may provide an optimal cutting height to decrease risk of low back disorders. As expected, the VSP 4x4 system showed the highest levels of trunk flexion due its low cutting height. The average sagittal trunk flexion for the VSP 4x4 was approximately 45°.

Figures 6 and 7 show the average percent of time spent within the specified ranges for the flexion/extension of the left wrist and trunk position in the sagittal plane respectively.

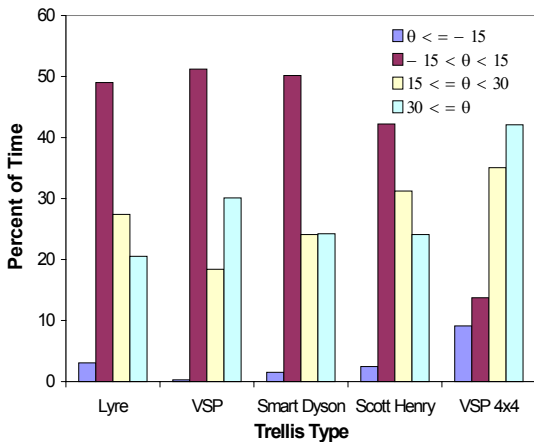


Figure 6. Percent of time spent in flexion/extension (left wrist).

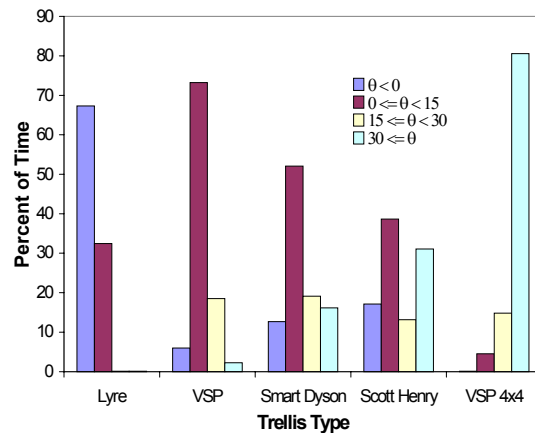


Figure 7. Percent of time in sagittal plane.

ANOVAs were completed to compare the average percent of time within a specific range (i.e., range 1) among all trellis systems. From Figure 6, significance was noticed for the flexion/extension of the left hand for ranges 2 and 4 only. The VSP 4x4 resulted in the lowest percent of time spent in the neutral range (range 2) with an average of 13.7%. The VSP resulted in the highest percent of time with an average of 51.2% in this range. The large percentage observed for the VSP suggests that the left hand is within a neutral range for at least 50% of the time.

The VSP 4x4 (left wrist) resulted in the highest percent of time in extreme extension (range 4) with an average of 42.1% compared with the other systems. The second prevalent range while pruning the VSP 4x4 was range 3 with an average of 35.1%. Therefore, 75% of total pruning time is spent in extension postures exceeding 15° for the VSP 4x4.

From Figure 7, the Lyre system resulted in the largest percent of time spent in sagittal extension compared with the other systems. The average percent of time spent in extension (range 1) was 67.3% compared with 17.1% for the Scott Henry, which resulted in the second highest percentage. The extension of the trunk may be harmful to the posterior elements of the lumbar spine (Adams et al., 2000). In addition, much of the cutting was performed with the arms above the shoulder. The body posture assumed was similar to that of reaching for an object above the shoulders causing extension of the trunk. Frost (Frost et al., 1999) defined occupational tasks that position the hands above the acromion as harmful to the shoulder. The elevated hand position causes impingement of the subacromial structures leading to MSDs of the soft tissues that comprise the shoulder. Therefore, the Lyre trellis would not be an ideal choice.

The VSP resulted in the largest percent of time spent in the neutral range (range 2) with an average of 73.2%. In contrast, the VSP 4x4 resulted with an average of 4.5%. Excluding the Lyre, a downward trend was noticed for the percent of time spent in range 2 as cutting height decreased. This clearly showed the direct relationship between trunk flexion and cutting height. As cutting height decreased, the amount of time spent in neutral postures decreased as flexion of the trunk was increased to accommodate the lower cutting height.

The percent of time spent in trunk flexion angles that exceeded 30° were significantly higher for the VSP 4x4 compared with the other systems. The VSP 4x4 averaged 81% compared with the second highest percentage of 31% for the Scott Henry.

Figure 8 shows the relationship between the flexion of the left wrist and flexion of the trunk. The coefficient of variation (R^2) was 0.82.

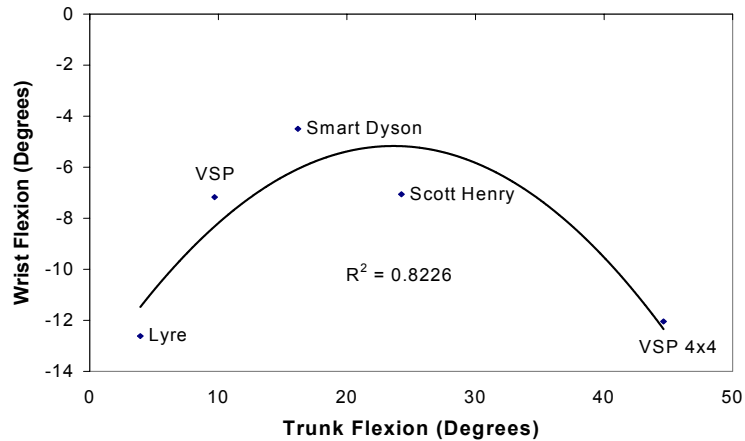


Figure 8. Left wrist flexion vs. sagittal trunk flexion.

The Lyre and VSP 4x4, both of which encompass relatively extreme trunk postures, result in the largest wrist flexion angles compared with the other trellises. Therefore, the implication from this result emphasizes the interaction effect of risk factors. The relatively large trunk flexion and extension angles in combination with increased wrist flexion increase the risk of developing MSDs of both the wrist and the back.

The results obtained from the subjective ranking of each trellis system are shown in Figure 9. The trellis systems were ranked from 1 (easiest) to 5 (hardest). The ranking of the systems were significantly different at the $p < 0.05$ level.

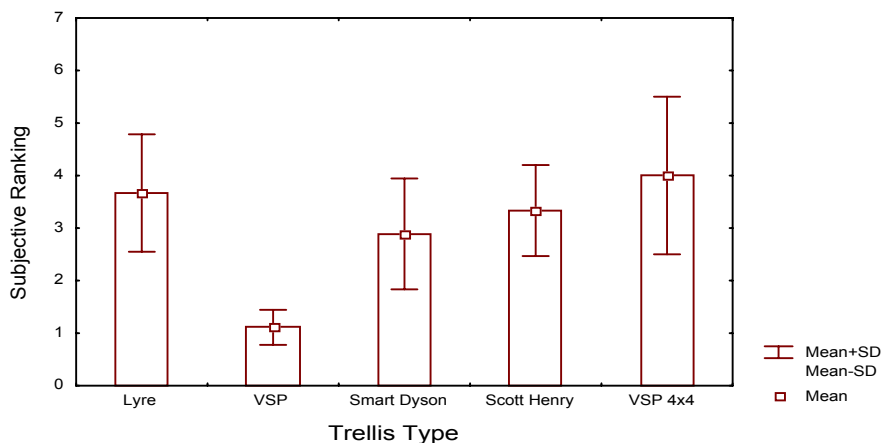


Figure 9. Subjective ranking of trellis systems.

The increased trunk flexion and increased wrist flexion angles make the VSP 4x4 system the least desirable from a MSD risk standpoint. From Figure 9, the subjective ranking of the trellis systems further validates this claim. The elicited responses were unfavorable for the VSP 4x4 system. A major complaint was the relatively low height of the system. The Lyre system would also be undesirable due to the combination of increased trunk extension, increased wrist flexion and increased arm flexion angles. The majority of the subjects complained about the effects of fatigue due to the excessive arm flexion required for reaching the higher branch height. The average trunk flexion values for the Smart Dyson and Scott Henry systems were significantly higher than the VSP. It must be noted that the overall body posture for pruning these systems consisted of squat/stoop postures. The subjective rankings of the trellis systems are overwhelmingly in favor of the VSP.

Conclusion

This study was able to demonstrate the relative risk of developing MSDs among five of the common trellis systems used in the winegrape industry. The significance of these findings may have important implications to vineyards that are currently considering to plant or re-plant new vines. Since there are no substantial differences with respect to grape quality or vine productivity among the variety of trellis systems, the findings of this study will be disseminated to advocate the use of the VSP.

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