Electrically heated cables protect vines from frost damage at early flowering

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Abstract

Background and Aims: Current methods of frost protection in vineyards involve fans, air heaters or sprinklers; each is limited by environmental constraints or available water. An alternative, all-electrical technique offers growers wider choice to match options with their vineyard operations. This study evaluates the ability of electrical heating cables, wrapped around the vine cordons, to protect inflorescences from frost damage.

Methods and Results: Five heating cable treatments in six replicates were applied to a 2-ha block of Sauvignon Blanc in the southern New England Region of Australia. Vines were subjected to a single −3°C frost event in November 2006 when at approximately 30% capfall. Non-heated vines suffered 41% (Control) and 46% (No heat) inflorescence loss. Those subjected to Low heat suffered a 28% loss, Medium-heated vines suffered a 16% loss and High-heated vines suffered a 13% loss. Qualitative scoring of the vines indicated that more than half of the Medium-/High-heated vines suffered no appreciate damage, whereas all non-heated vines suffered some form of potential crop loss or damage.

Conclusion: Electrical heating cables of minimum 10 W/m power rating were found to significantly reduce frost damage to inflorescences at 30% capfall.

Significance of the Study: At approximately 43 kW/ha, electrical heating cable offers an alternative frost protection method for small vineyards.

Keywords: *frost protection, grapevine, heating cable*

Introduction

Late spring frosts are one of the greatest challenges facing grape growers in cool-climate regions (Jackson and Spurling 1988, Wolf and Johnson 1993). Extracellular ice crystallisation removes water from xylem vessels, and as crystallisation spreads into the adjacent cell walls, osmotic pressure acts to remove water from the cytoplasm of neighbouring cells. The subsequent dehydration can cause protein and nucleic acid denaturation (Pearce 2001).

There are a number of active and passive options of frost protection (reviewed by Snyder et al. 2005) used worldwide. Beyond appropriate site and variety selection (passive options), the grape and wine industry relies on three main active alternatives: frost fans/helicopters, sprinklers and heaters. Recent interest, in Australia in particular, is also being shown in the use of chemical spray-on protectants (Wilson and Jones 1983).

Frost fans work by mixing low level air with warmer air from higher in the inversion. They are generally noisy, and while designed to comply with Environmental Protection Agency (EPA) (or equivalent), noise standards are generally unpopular in proximity to built-up areas. A single frost fan covers approximately 7–10 ha, but their effectiveness is strongly dependent on vineyard topography and layout and on the strength of the inversion layer (Wilson 2001). Some regions in both NZ and Australia utilize hovering helicopters. These too have attendant noise issues as well as additional risk factors associated with coordinating multiple helicopters in sometimes congested airspace. There are also large operational costs associated with keeping helicopters and staff on standby.

Overhead sprinklers reduce the impact of frost by relying on the latent heat energy released by water when it freezes on contacting the surface of grapevines (Snyder et al. 2005). Undervine sprinklers maintain the ground temperature near 0°C to increase long-wave radiation and sensible heat transfer to the plants. To be effective, the water application (either via mist or larger droplets) must continue for the duration of the frost conditions. Frost sprinklers can consume large amounts of water (up to 0.03 ML/ha/hr for an application rate of 3 mm/hr) and, as water resources are limited, face an unknown future. Furthermore, the majority of Australian vineyards are either drip irrigated or not irrigated; therefore, it is likely that vineyard owners would face the need to modify their systems necessary to meeting new water supply conditions.

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Heaters raise the local air temperature to create a warm air cushion in the vicinity of the vines (Snyder et al. 2005). Their effectiveness is critically dependent on the type of air conditions in the vineyard (e.g. a weak or a strong inversion). Vineyard designs, for example, the location of shelter belts, sheds and topography, influence the required density and distribution of heaters necessary to afford maximum protection. The number and configuration of heaters, for example, central or distributed networks and associated operation and maintenance costs, fuel prices for liquid fuel heaters and their environmental impacts, influence their desirability as a frost protection option.

The practical value of spray-on frost protectants remains unknown, primarily because of a lack of data concerning in-field effectiveness. In a review of the literature, Wilson (2001) suggests that spray-on protectants may provide a practical gain in freezing temperature of less than 2°C; however, there has been no scientific confirmation of the effectiveness of spray-on protection in the field; Wilson (2001) reports an *in vitro* effect only. Moreover, growers in marginal frost areas, where frost incidence and degree are uncertain, may need to spray on a routine rather than on an 'as required' basis, further diminishing the commercial and practical value of this approach.

In this paper, we evaluate the use of an alternative, all-electrical method; the use of electrically heated cables for protecting vines from frost damage. The concept, originally the subject of a French patent dating back to 1998 (Heurteau 1998), involves stringing electrical heating cable along the main trellising wire/cordon of grapevines. The French patent suggests that the mechanism by which the heated cable protects frost is via direct conduction of heat into the vine cordon wood and then to the buds/shoots via conduction through the sap.

Material and methods

The trial

An electrical heating trial was established in a 2-ha block of cv. Sauvignon Blanc (planted 1998) in Peterson's Armidale Vineyard located in the southern New England region of Australia (Lat 30° 31.7′ S, Long 151° 31.0 E). The vines were spur-pruned on vertical shoot positioned (VSP) trellising. The site was selected on the basis that the region experiences regularly recurring late spring frosts. The trial block (and indeed the entire vineyard) 'falls' towards the northeast with a uniform 6% slope.

The trial was designed with replicated, randomised heating treatments applied to individual panels of three vines. Vine spacing was 1.8 m, each panel was 5.4 m long and row spacing was 3.0 m. The trial consisted of three rows with two replicates of five treatments per row, giving a total of five treatments × six replicates per trial. Each trial panel was separated by a minimum of one buffer panel, and each row separated by a buffer row. The treatments comprised Control (no cable), No heat, Low heat, Medium heat and High heat.

The cables under evaluation were 240 V, single-core heating cable (Deviflex, DEVI A/S, Vejle, Denmark) of various ratings (W/m) as summarized in Table 1. The cables were wrapped as a helix around and along the vine cordons encompassing both the cordon and cordon wire (Figure 1). External power infrastructure was comprised of a 68-kVA pole-top transformer, sub-mains and switching box. The heating cable in each heated panel was electrically connected to a single-phase 240-V busbar which was suspended along the irrigation dripper wire (Figure 1). Those treatments involving 'No heat' did have a cable installed, but they were not electrically connected (i.e. not heated). The 'Control' and 'buffer' panels did not have a cable installed.

Cable surface temperatures (Low, Medium and High) were determined by selecting an appropriate combination of cable rating (W/m) and cable length. Following installation of the cables, measurements of cable surface

Table 1. Summary of cable performance characteristics.

Treatment	Cable rating (W/m)	Cable surface temperature (°C) relative to ambient air temperature
Low heat	5	+6
Medium heat	10	+12
High heat	15	+17

Cable surface temperatures are given relative to ambient air temperature and were verified on two different nights, at ambient air temperatures of −4 and −8°C, respectively.

Figure 1. Two photographs illustrating the wrapping of (red) heating cable along (a) single vine (b) and an entire treatment panel. Note that the heating cable is wrapped around the vine cordon/cordon wire and the ends are connected to the (white) busbar which is attached along the dripper pipe in (b).

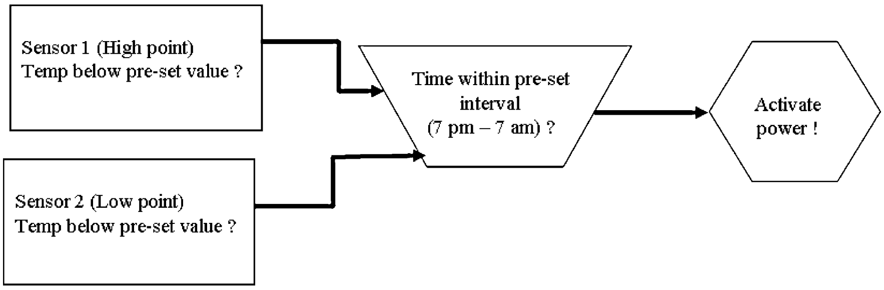

Figure 2. Switching logic used to actuate the heating cables.

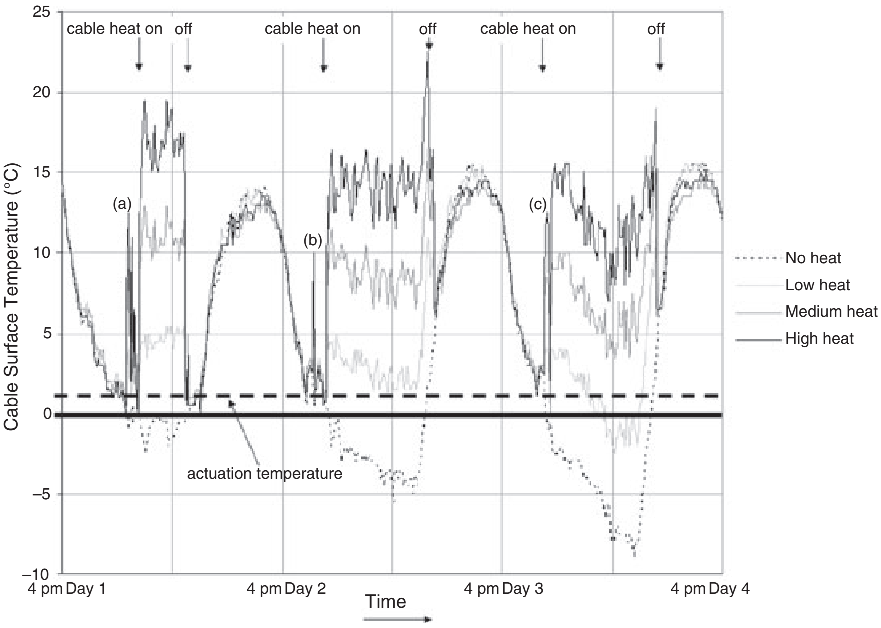

Figure 3. Continuous temperature record (10-minute intervals) over a 3-day period. Sensors were located on all cable treatments. 'No heat' is equivalent to ambient temperature. Horizontal dashed line indicates the actuation temperature (here set to +2°C) and solid line indicates 0°C line. Note diurnal variation in temperature and cables switching 'on' and 'off'. Labels (a), (b) and (c) indicate unwanted switching pulses occurring at actuation temperature.

temperatures were performed under sub-zero conditions (midwinter) to gauge system performance. Cable ratings and resulting surface temperatures (measured relative to ambient air temperature) are summarized in Table 1.

Electrical control of the heating trial was facilitated using the combination of a timer switch and two ambient air temperature sensors. One of the temperature sensors was located at a 'high point', midway up the sub-mains pole, at a height approximately 4 m above the elevation of the trial blocks. A second sensor was located at a 'low point', corresponding to approximately 3 m below the elevation of the trial blocks, in a gully 50 m southeast of the trial location. The timer clock was installed in the sub-mains controller box. The control logic is summarized in Figure 2.

Cable and ambient air temperature were monitored using miniature *eTemperature* loggers (OnSolution Pty Ltd, Sydney, Australia), which were programmed to log external temperature at 10-minute intervals over a period of 4 weeks. The button loggers were physically attached to all heating cables using white insulation tape to minimize radiant heating or cooling effects. An additional sensor was installed inside a radiation screen at one corner of the trial site to measure ambient air temperature and this was confirmed to be the same as that derived from a button logger attached to a 'No heat' treatment cable. The switching configuration was tuned to ensure the treatments were switched on when the ambient (cordon level) temperature dropped to +2°C (Figure 3).

One feature of the actuation process evident in Figure 3 is that as the air temperature approaches the actuation temperature, small fluctuations, probably resulting from air currents, results in the system suffering switching pulses (labels (a), (b) and (c) in Figure 3). It is very likely that such pulses could be avoided if the thermal mass of the sensing probes used to control the switching circuit is increased.

Scoring of frost damage

Two manual scoring procedures were conducted 2 weeks after the frost event to quantify the impact of the frost on each of the trial vines. In both scoring systems, the three individual vines within each treatment panel were scored separately.

Quantitative scoring involved counting the number of viable inflorescences and the number of frost-damaged inflorescences (defined as >33% necrosis) present on each vine and converting this to percentage loss using

$$\text{Inflorescence loss (\%)} = \frac{\text{Number of damaged inflorescences}}{\text{Total number of inflorescences (damaged + viable)}} \times 100$$

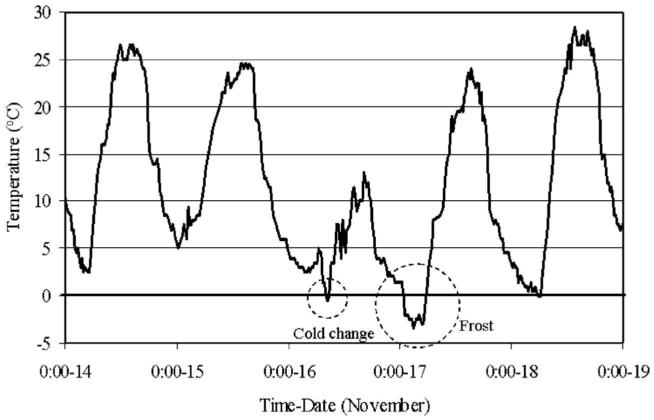

Figure 4. Six-day site temperature log centred on the 17 November frost event (circled). Note that a brief 'cold change' (also indicated) occurred during the previous day. The 0°C temperature line is marked as a horizontal line.

Treatment effects were compared using analysis of variance (ANOVA)/Duncan's multiple range test (Duncan 1955) on arcsin transformed data to compare the per cent crop loss between each of the treatments.

A semi-quantitative visual appraisal of each vine was also conducted by an independent viticulturist (Chris Sloane, New England Vineyard Services). The viticulturist was presented with each vine in every panel in such a way that it was not possible to ascertain whether the vines were subjected to either the heated or non-heated protocols. The semi-quantitative assessment rated overall vine damage (inflorescence and shoot damage) on a scale of 0 to 5, where 0 indicated no visible damage, 1 through 4 indicated 20, 40, 60 and 80% damage by proportion to total numbers of inflorescences/shoots, respectively, and 5 indicated 100% damage. The damage scores were subsequently normalized to reflect the relative proportion of vines damaged across the trial.

Results

The frost event

The New England region did not experience a late spring frost until 17 November 2006, 8 weeks after budburst and when the trial vines were at approximately 30% capfall (pre-flowering) stage of development. The average vine shoot length was 39 cm. The frost occurred early in the morning following a cold change that moved through the region on the previous day.

A 6-day site temperature log, centred on the 17 November frost event, is given in Figure 4. The temperature dropped below zero between 12.44 a.m. and 5.44 a.m. with a minimum temperature of −3°C. The temperature remained below −2°C for a period of 4 hours.

The true extent of visible vine damage and crop loss did not appear until 7 days following the frost, and after a further 7-day 'confirmation' period, scoring of vine damage was conducted. Example photographs of a vine subjected to the High heat treatment and another vine that was not heated are given in Figure 5. The unheated vine is characterized as having more visible damage to external foliage (leaves and shoot tips) as well as damage to inflorescences.

Figure 5. Photographs of individual vines subjected to (a) High heat and (b) unheated.

Table 2. Mean per cent inflorescence damage for each treatment.

	Per cent inflorescence damage
Control	41.3[a]
No heat	46.3[a]
Low heat	28.2[b]
Medium heat	16.5[c]
High heat	13.1[c]

Treatments followed by the same (superscript) letter do not significantly differ from one another ($P = 0.05$).

The results of the ANOVA/multiple range test for each treatment are summarized in Table 2 and there was a significant ($P < 0.05$) treatment effect observed. Control and No heat treatments showed significantly ($P = 0.05$) greater damage than each of the heated treatments. Low heat also showed significantly ($P = 0.05$) more damage than either of the two higher heat treatments.

A histogram of the per cent inflorescence loss for each of the heat treatments is plotted in Figure 6.

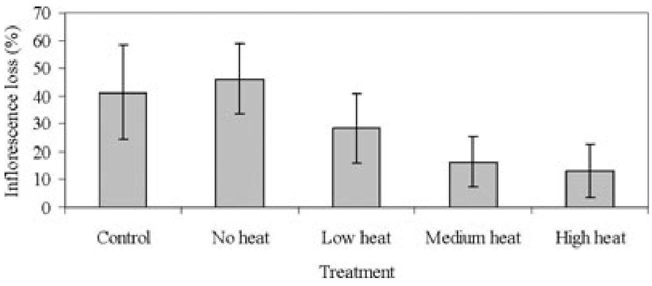

Figure 6. Average damaged inflorescences (standard deviations marked as error bars) for each of the treatment groupings in cv. Sauvignon Blanc.

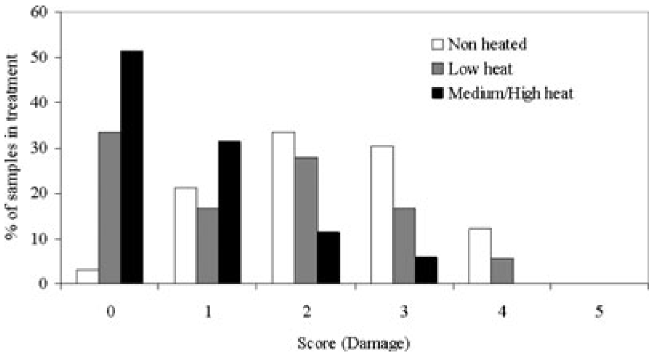

Figure 7. Normalized histogram of vine scores for each treatment group (colour coded). Vine damage was scored on the basis of 0 (no damage or inflorescence loss) to 5 (100% damage and inflorescence loss). Each treatment class sums to 100%.

According to Table 2 and Figure 6, non-heated vines, namely the Control and No heat treatments suffered substantially greater inflorescence loss than those subjected to Low and Medium heat, whereas High-heated vines suffered the least loss.

The results of the semi-quantitative assessment of overall vine damage are summarized in Figure 7. Here, the data have been grouped according to non-heated (i.e. Control and No heat vines), Low heat and Medium/High Heat. Those vines that were not heated scored much higher damage than those subjected to Low heat, while the Medium-/High-heated vines scored the least damage. More than half (i.e. 51%) of the Medium-/High-heated vines suffered no visible crop loss or damage compared with 33% of the vines under Low heat, and all vines in the non-heated treatments suffered some form of inflorescence loss or damage.

Discussion and conclusion

Both the quantitative measurement of inflorescence loss and semi-quantitative scoring of vine damage in the cv. Sauvignon Blanc trial yielded consistent trends; unheated vines suffered most inflorescence loss/damage, the Low-heated vines suffered intermediate loss/damage, and the Medium-/High-heated vines the least loss/damage. While the quantitative (inflorescence count) assessment of the High-/Medium-heated vines yielded average losses of 13% (High heat) and 16% (Medium heat), the qualitative scoring rated more than half the vines in these treatments as having no damage/loss at all. This variability is likely related to the exclusion from the count by the independent viticulturist of dead inflorescences not related to frost (likely due to bunch necrosis). However, in the quantitative assessment, all dead inflorescences were scored on the assumption that they were killed by frost. Thus, the 13–16% inflorescence loss experienced in the Medium-/High-heated vines may actually be an overestimation.

The original French patent (Heurteau 1998) describing the use of heated cables ascribed the mechanism of heat transfer from the cable to the buds to thermal conduction via the sap. This mechanism is plausible for buds in the very early stages of post-dormancy, as the distance between the cable and buds in spur-pruned vines is of the order of 2–5 cm and, in the case of cane-pruned vines even less if the canes are wrapped around the cable when tied onto the cordon wire. However, in this present work, the frost occurred 8 weeks post-budburst, the average shoot length in the Sauvignon Blanc vines was 39 cm, the canopy was established and the distance from the cable to the base of the inflorescence bunches was 15 cm or more. Pre-dawn measurements/modelling in grapevines conducted by Green et al. (2003) indicate heat-pulse sap flow speeds of approximately 30 cm per hour. Certainly, if mass transfer (via sap flow) dominated over conduction as the heat transfer mechanism within the vines, the inflorescences and shoots would be expected to receive the heated sap at least half an hour after cable actuation. Assuming that enough heat from the cables can be coupled into the sap of the shoot via the periderm (which in itself is likely to be a good thermal insulator), and is conducted to the inflorescences, the temperature rise occurring at the base of each inflorescence bunch is likely to be less than the source cable temperature owing to radial diffusion of the heat as it propagates along the shoots. Given the advanced stage of canopy development in this work, and the effective level of protection afforded by the distant heating cables, it is quite likely that the overarching canopy may have trapped warm air, thereby contributing to the effectiveness of the heated cable treatments. Further experimental and theoretical investigation of the within-shoot conduction versus within-canopy convection processes is necessary to fully understand the frost protection mechanism.

The electrical design of this experiment necessitated use of a busbar, placed along the dripper cable, from which to draw power for each treatment panel. In practice, the cable would only need to be attached end-to-end along each row. Wrapping the cables around the vine cordons was found to require approximately 1.3 m of cable per metre of cordon length. Assuming a 3-m row spacing, this equates to approximately 4.3 km of cable per hectare. Based on the cable rating of 10 W/m for the Medium heat treatment, power consumption for a heated cable configuration such as that used in this investigation would be approximately 43 kW/ha. This consumption would likely limit the application of this technology to smaller vineyards. However, as frosts generally occur during the off-peak power periods, there are opportunities of added cost savings through reticulating power, for example, from a nearby winery.

From a practical management perspective, obvious care is required when hand harvesting or pruning vines in the vicinity of the cables. Indeed, the only cable damage experienced in this work resulted from 'careless' pruning, but the severed cable was easily repaired. Obviously, if applied to cane-pruned vines, it would be necessary to remove the cables from the old cane and rewind onto the new ones. While prudence suggests that it may be necessary to remove the cables from the vines prior to mechanical harvesting, our own experience has shown that if the cables are wrapped onto the cordons in short 'reaches' of loop/counter-loop, then it is possible to unwind and drop the cables onto the ground and run a mechanical harvester safely over the vines.

Author's postscript

The vines in the trial site were extensively damaged by a hail storm that passed through the New England region on 22 December 2006. No fruit was harvested in the subsequent harvest period.

Acknowledgements

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References

Duncan, D.B. (1955) Multiple range and multiple F tests. Biometrics **11**, 1–42.

Green, S., Clothier, B. and Jardine, B. (2003) Theory and practical application of heat pulse to measure sap flow. Agronomy Journal **95**, 1371–1379.

Heurteau, J.P. (1998) Dispositif et procede de procede de protection des vegetaux, notamment des vignes, contre le gel (Protection arrangement for vines against spring frost). French Patent FR2754672A1.

Jackson, D.I. and Spurling, M.B. (1988) Climate and viticulture in Australia. In: Viticulture volume 1: Resources. Eds. B.G. Coombe and P.R. Dry (Winetitles: Adelaide) pp. 91–106.

Pearce, R.S. (2001) Plant freezing and damage. Annals of Botany **87**, 417–424.

Snyder, R.L., de Melo-Abreu, J.P. and Matulich, S. (2005) Environment and Natural Resources Series 10. Frost Protection: Fundamentals, Practice, and Economics, Volume 1 (Food and Agriculture Organisation of the United Nations: Rome).

Wilson, S. (2001) Frost management in cool climate vineyards. Final report to Grape & Wine Research and Development Corporation (Project UT 99/1).

Wilson, S.J. and Jones, K.M. (1983) Cryoprotectant effects of concentrations of polyethoxy polymer (Teric 12A23B) on blackcurrant flowers. Scientia Horticulturae **19**, 245–250.

Wolf, F. and Johnson, W. (1993) Grapes for Northern Nevada: University of Nevada, Reno Grape Trials, 1982–1992. Fact Sheet 93–14 (University of Nevada, Cooperative Extension: Reno, USA).

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