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Feasibility study of a passive temperature elevation system for in-vineyard climate change research

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1 Introduction

Successful wine-grape production is highly dependent upon regional climate and weather conditions during growing seasons, with grape berry (and subsequent wine quality) composition being particularly sensitive to temperature during development and ripening phases. Anthropogenic-driven climate change manifested as increasing global temperatures, may affect grapevine phenology by advancing budburst, flowering, and accelerating berry development. For example, climate change simulations using a model for the developmental stages of Riesling and Gewurztraminer in Alsace, predict an earlier onset of véraison by up to 23 days by the end of the 21st century, with a mean temperature increase of 7°C during the 35 days post-véraison period (Duchene et al. 2010).

One of the clearest relationships between temperature and fruit quality concerns grape berry acidity, as higher temperatures decrease the concentration of organic acids (malic in particular), desynchronising sugar and organic acid metabolism (Rienth et al. 2016) prior to harvest. This is a major concern for cool-climate grown Marlborough Sauvignon blanc given the significant contribution that acidity makes to the wine style and consumer expectation. Indeed, anecdotal reports by winemakers for vintage 2019 as an example, reported Marlborough Sauvignon blanc wines from some sub-regions having become increasingly ‘Riesling’ like (less acidity, more neutral aromas and increasing stone fruit characters), following a particularly warm growing season.

Thus, in order to quantify previously modelled climate change impacts and understand adaptation timeframes with more certainty for the Marlborough region, a small pilot monitoring and feasibility study was established during the 2021–22 growing season to:

1. Design, construct and test the efficacy of an in situ and ‘real world’ vineyard-deployed passive temperature elevation frame (PTEF) system, to simulate future warmer growing conditions;
2. Make preliminary observations of the effects of any warming on vine phenology and date of harvest.

Here we report our findings and preliminary observations from the 2021–22 season.

2 Materials and methods

2.1 Feasibility study site

The initial feasibility study was located at the Nelson Marlborough Institute of Technology research vineyard on the north-eastern outskirts of Blenheim (41°30'09.42''S, 173°58'03.87''E. Elevation 3 m). Originally the intention had been to locate the study at the Marlborough Research Centre (MRC) Rowley Research Vineyard, but due to the August 2021 COVID-19 lockdown leading up to bud-burst, subsequent delays in the supply of construction materials, and to overcome some initial logistical challenges, this alternative site was chosen. The soil type at the site is classified as Kaiapoi and characterised as a deep stoneless, imperfectly drained, silty loam alluvium (https://smartmaps.marlborough.govt.nz/smapviewer/?map=eeeff21e2a664dbeba7e07d5b177d593).

At the site, the variety Albariño, clone Plansel 635 on Riparia Gloire rootstock was the only white grape variety available, and so chosen in substitution of Sauvignon blanc for this initial study, and because it would be expected to respond to additional warming in a similar manner to Sauvignon blanc. In common with regional commercial practice, vines had been planted in spring 2013 in a north–south row orientation, with 1.5 m between vines and 3.0 m between rows, and lower fruiting wires set 0.95 m from ground level. Vines were managed using a vertical shoot positioned training system, sprayed routinely to control pests and diseases, trimmed and leaf plucked as required during the growing season. Vines were drip irrigated as required, and the inter-row was a mix of planted grasses and weed species. Vines were netted against bird damage from the onset of véraison to harvest.

The vineyard is accredited under the official New Zealand Sustainable Winegrowing Programme (https://www.nzwine.com/en/sustainability/swnz).

2.2 Passive temperature elevation frame (PTEF) system

Passive temperature elevation frames (PTEFs) designed for the in situ passive warming of bunch zone and canopy throughout the growing season (Figure 1 below), were based on the original concept and design of Sadras and Soar (2009), but with local modification.

Triangular PTEF sub-frames with a base footprint measuring 1.4 m by 2.4 m were constructed from 32-mm alloy angle (Cuddons, Marlborough, New Zealand) bolted together, and with an approximate 45° angled clear corrugated polycarbonate roof 1.5 m by 2.4 m (Ampelite Solasafe, Mitre 10, New Zealand) to passively capture and maximise incoming radiation. With the locally modified dimensions, three sub-frames placed end to end on either side of a grapevine row are sufficient to span a typical vineyard bay (post to post) length of 7.2 m (e.g. Rowley Research Vineyard). Further, with the apex of PTEFs at 0.9 m from ground level and just below typical fruiting wire height, there is no direct modification of the fruit-zone or canopy environment. Instead, a horizontally adjustable 300–400 mm apex gap between facing PTEFs (either side of the row/canopy), allows passively warmed air from within PTEFs to funnel up and through the developing bunch-zone and canopy, thereby generating a future climate warming treatment.

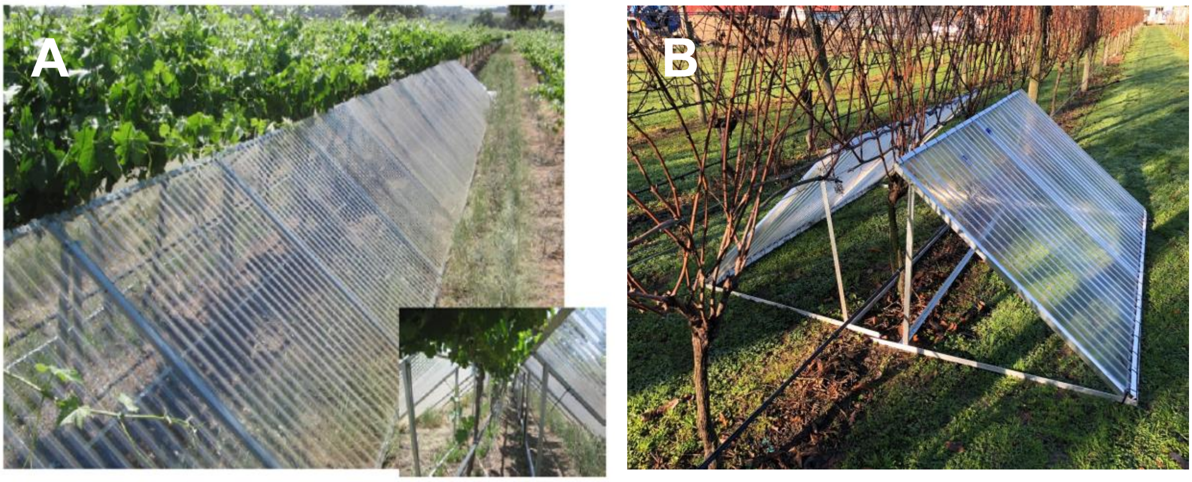

Figure 1**.** Passive temperature elevation frame (PTEF) systems for simulating warmer growing season temperatures; (A) image taken from Sadras and Soar (2009), (B) two locally developed framed sub-units forming part of the PTEF deployed in the Nelson Marlborough Institute of Technology research vineyard during 2021–22.

2.3 Research treatments

Vines were cane pruned by Nelson Marlborough Institute of Technology (NMIT) students the previous winter to a potential of four bi-lateral canes, and had been laid down to fill the fruiting wire.

As a feasibility study with initially only sufficient sub-frames to construct one complete PTEF system to span one entire bay (i.e. no PTEF replication), the study was applied across three adjacent bays of vines in one row, each bay consisting of four vines. Plots within these bays consisted of single individual vines, and treatments were replicated four times. Control (ambient temperature) plots were allocated as the two middle vines in both the northernmost and southernmost of the three bays. The PTEF treatment (elevated temperature) was, due to its physical linear construction, allocated across the entirety of the four vines in the middle bay, with any unallocated vines in the control bays acting as buffer vines between treatment plots (Figure 2).

The PTEF was deployed in the vineyard on 9 October 2021, 3 weeks after bud-burst. The PTEF was weighted down and kept in position using strategically placed 20-L water containers, electrical zip ties and steel fencing posts. To retain passive heat, open triangular ends of the PTEF were closed in with clear polycarbonate sheeting cut to fit (Coreflute, Mitre 10, New Zealand). The PTEF remained in situ until 5 February 2022 (just prior to véraison), but for periodic removal approximately every 10 days (from late afternoon to mid-morning the following day) to permit tractor passes for the standard seasonal vineyard management activity.

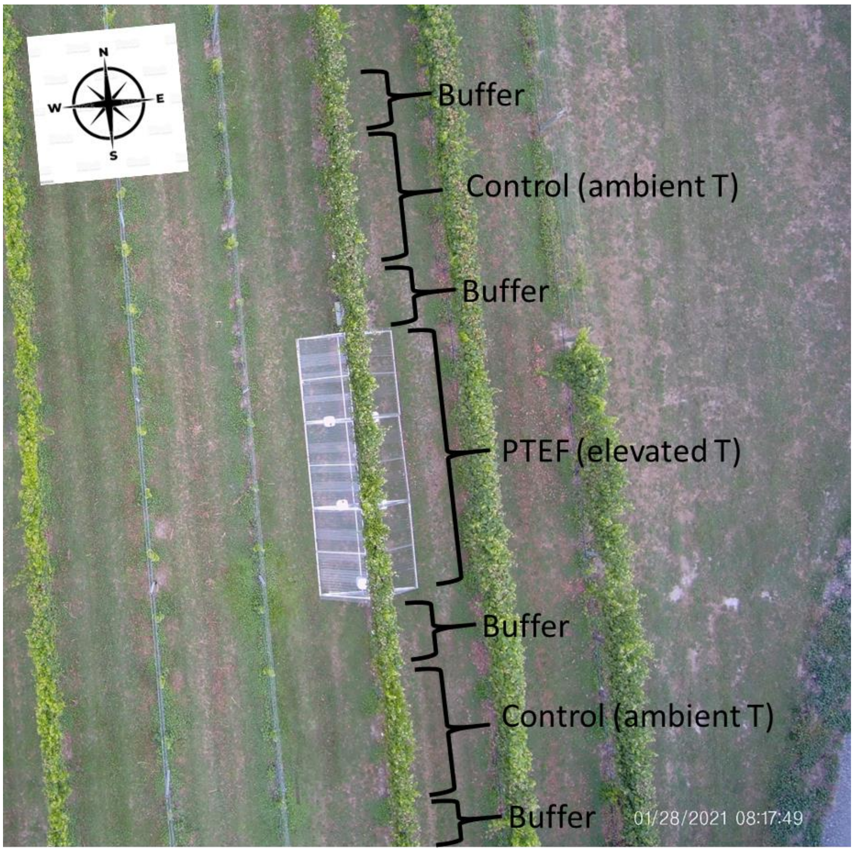

Figure 2. Aerial view of the feasibility trial located at the Nelson Marlborough Institute of Technology (NMIT) research vineyard, showing the arrangement of control and PTEF treatments, and location of interspersed buffer vines. For scale, the length of the PTEF system was 7.2 m. Aerial image courtesy of Dr Stewart Field, NMIT.

2.4 Soil and vine measurements

2.4.1 Canopy and soil sensors

On 8 November 2021, two temperature and humidity loggers (Lascar EL-USB-2, RS Components, New Zealand) recording every 5 minutes, were placed within the bunch zone between treatment vines; one in the northern-most control bay, and one in the middle PTEF treatment bay. Three additional temperature sensors (Tinytag TGU-4020, RS Components, New Zealand) also recording at 5-minute intervals, were all placed on the soil surface, one immediately below the previous control bay bunch zone sensor, and the others within the centre of the PTEF treatment sub-frames on either side of the canopy row. All sensors were housed in individual white plastic solar radiation shields (Stevenson screens).

Six previously calibrated volumetric soil moisture sensors (CS616 Water Content Reflectomer, Campbell Scientific, Logan, USA), which integrate measurements to a depth of 300 mm, were installed in the vine row on 12 November 2021, two each in the northern- and southern-most control vine bays, and two in the middle PTEF vine treatment bay. At the same time, a single soil temperature sensor measuring at a depth of 100 mm was placed in the vine row and centre of each of all three bays. All sensors were connected to a logger (CR10X, Campbell Scientific, Logan, USA), which recorded measurements every five minutes and which were output onto the logger as single hourly averages. Measurements were checked and downloaded periodically.

2.4.2 Flowering assessment

Flowering assessments were undertaken approximately twice a week from the onset of flowering (mid-November) until completion in early December 2021. Five shoots per vine were randomly selected and the percentage of open caps on the basal inflorescence and apical inflorescence (where present) were recorded for each shoot.

2.4.3 Véraison assessment

On five occasions from and including 8 February to 24 February 2022, the basal berry on each of 10 bunches randomly selected on each treatment vine, was gently squeezed, and given a berry softening score of either still hard (=1), just beginning to soften (=2), or soft (=3).

2.4.4 Grape maturity assessment

Grape maturation was assessed approximately weekly from 15 February 2022 on six occasions by collecting a 30-berry sample (five berries selected from top, middle and bottom) from each of six randomly selected bunches per treatment vine. The berry samples collected in small plastic zip-lock bags were weighed, hand-squashed within the bag, and then sieved to recover available juice. Soluble solids content (measured as °Brix) was determined using a Mettler Toledo RM40 hand-held refractometer.

2.4.5 Harvest parameters

Harvest date for the variety Albariño was determined to be at a target total soluble solids (TSS) of 22.5 °Brix, the rate of progress to target being tracked taking account of weekly grape maturity assessments and accounting for late season intermittent rainfall and overcast growing conditions. On each harvest date (which was different for the two treatments), fruit from each individual vine treatment plot were hand harvested, and bunches counted and weighed. From the fruit of each harvested vine a further 30-berry vineyard sample was taken to confirm that harvest target TSS had been reached.

2.4.6 Statistical analysis

Data from bunch zone and soil temperature measurements, and soil moisture sensors were analysed for treatment effects using a simple one-way ANOVA (Microsoft® Excel®). Data from flowering, véraison and grape maturity assessment were analysed by treatment and time using two-way ANOVA (Microsoft Excel®).

3 Results

3.1 Bunch zone and soil temperatures, soil moisture content

Across the 4-month period that treatments were applied (9 October 2021 to 5 February 2022), there was a highly significant (p<0.001) effect of the PTEF treatment in elevating mean bunch zone temperature to 19.3°C compared with 17.9°C in the ambient control. This equates to a mean difference of 1.4°C between treatments through the growing season (see Figure 3 showing a snapshot time period around flowering). During the same 4-month period and, respectively, for the control and PTEF treatments, minimum temperatures recorded in the bunch zone were 1.0 and 1.5°C, with maximum bunch zone temperatures of 34.0 and 41.5°C.

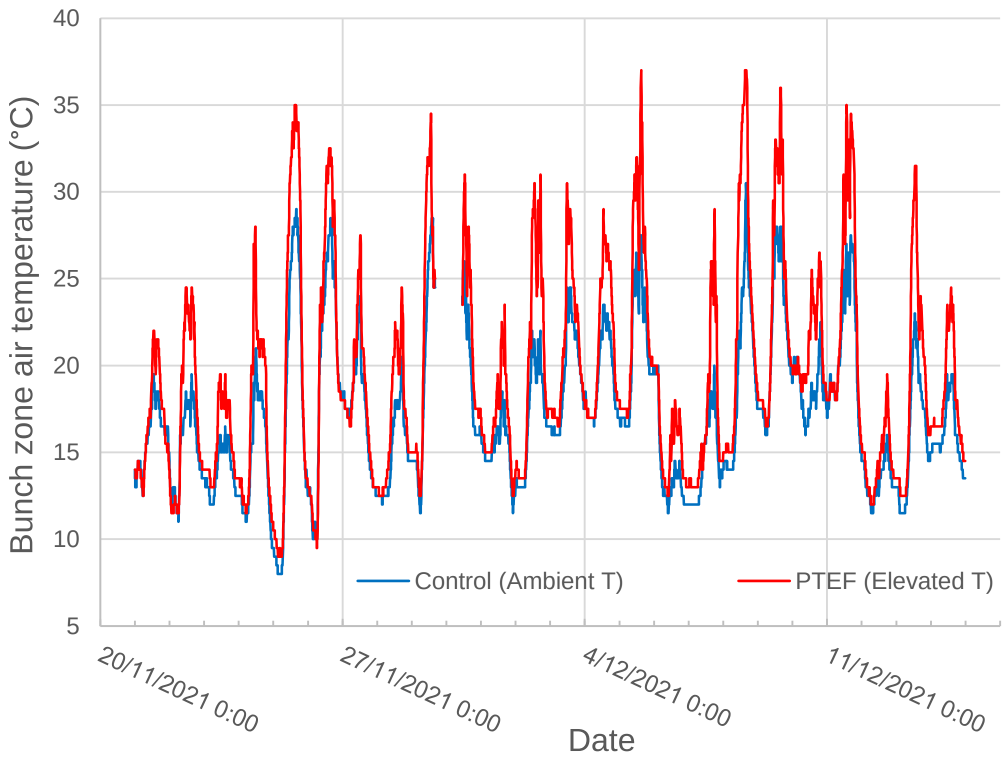

Figure 3. Temperature logger output for sensors placed in the bunch zone at 1 m above ground level in one control bay (ambient temperature (T)) and the single PTEF treatment bay (elevated T). Note that at 1 m from ground level in the passive temperature elevation frame (PTEF) treatment, this also corresponded to a sensor position in the bunch zone 100 mm above the PTEF apex from which the flue of potentially passively warmed air flowed up through the canopy. The snapshot timeframe shown corresponds to mid- to late-flowering.

Despite the PTEF treatment increasing mean bunch zone temperature by 1.4°C, this was not evenly spread within any diurnal (day/night) period, as highlighted by the temperature differential (PTEF (elevated T) – Control (ambient T)) between treatments (Figure 4), and shown for the same flowering time period.

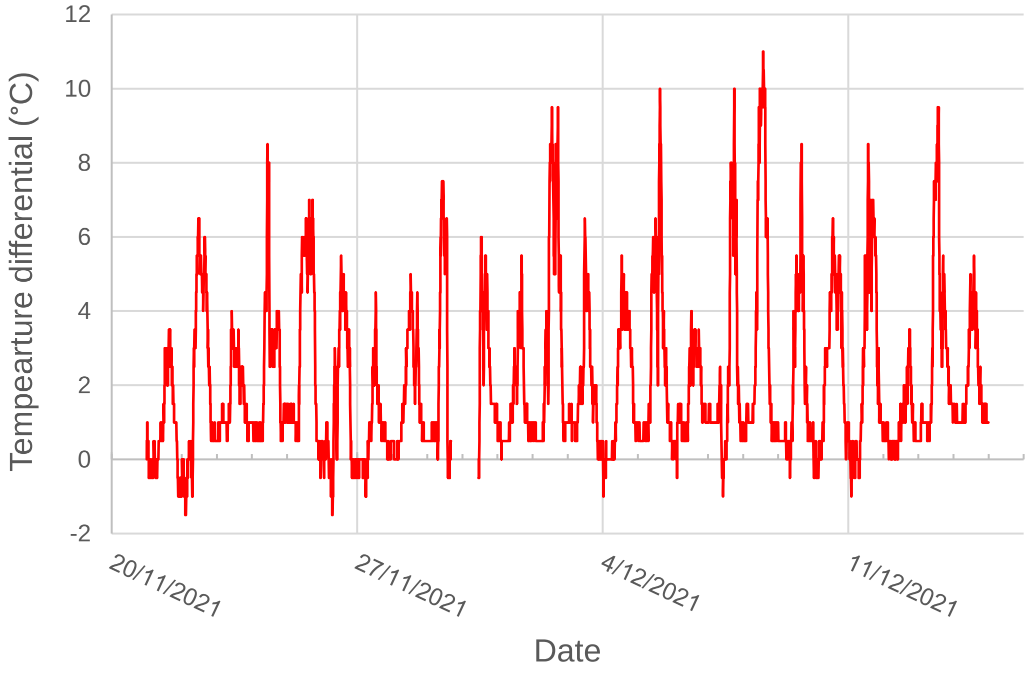

Figure 4. The temperature differential (passive temperature elevation frame (elevated T) – control (ambient T)) for bunch zone temperature between treatments and for same mid- to late-flowering time period presented in Figure 3.

Figure 4 clearly highlights the bunch zone temperature differential between control and PTEF treatments, and which variably ranges from as little as 3.0°C to almost 11.0°C for any given diurnal period. Also indicated (and also observable in Figure 3) is that the greatest temperature differentials occur during daylight hours, with temperatures rapidly dropping off in the PTEF bunch zone to match that of control within 1–2 hours after sundown, and for the entire period prior to next sunrise.

From approximately mid-November 2021 to mid-February 2022 (Figure 5), there was a highly significant ($p<0.001$) effect of the PTEF treatment system in elevating mean soil temperature within the vine row at 100 mm depth to 23.2°C compared with 20.4°C in the ambient control. This equates to a mean difference of 2.8°C between treatments through the whole monitoring period. Respectively, for the control and PTEF treatments and for the same time period, minimum soil temperatures at 100 mm depth were 15.7 and 16.8°C, with maximum soil temperatures of 26.3 and 30.9°C.

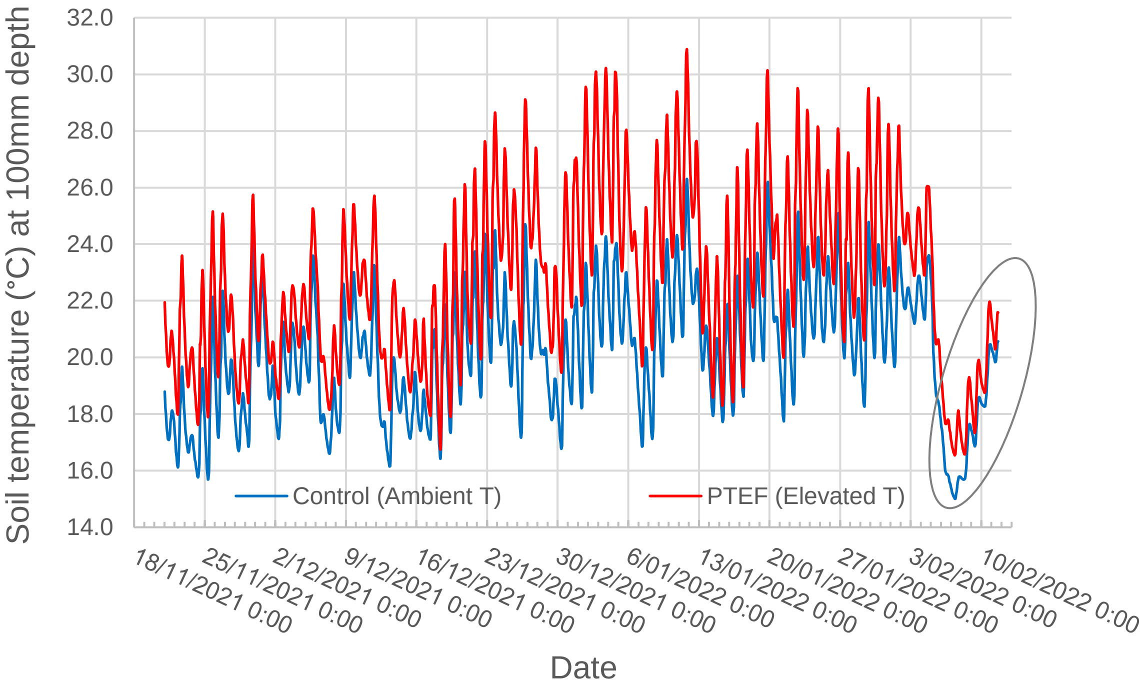

Figure 5**.** Soil temperature measured at 100 mm depth within the vine row for control (mean of four sensors) and passive temperature elevation frame (PTEF) (mean of two sensors) treatments from 21 November 2021 to 12 February 2022. The grey ellipse highlights the time from 5 February 2022 after which the PTEF treatment had ended (further referenced and discussed in the text below).

Whilst there were diurnal patterns of soil warming and cooling in concert for both treatments, absolute night-time soil temperatures between treatments never converged by pre-dawn, demonstrating good night-time temperature buffering capacity of the vineyard soil. Also of note is that days with lower absolute soil temperature ranges in concert for both treatments, may have coincided with overcast conditions and rainfall events (see rainfall data in Figure 6 below). The only time that soil temperatures for both treatments did converge, was after 5 February 2022 when the PTEF treatment was removed (Figure 5; highlighted by grey ellipse). This observation also confirms that soil temperature sensors still remained closely calibrated following almost 3 months of vineyard deployment.

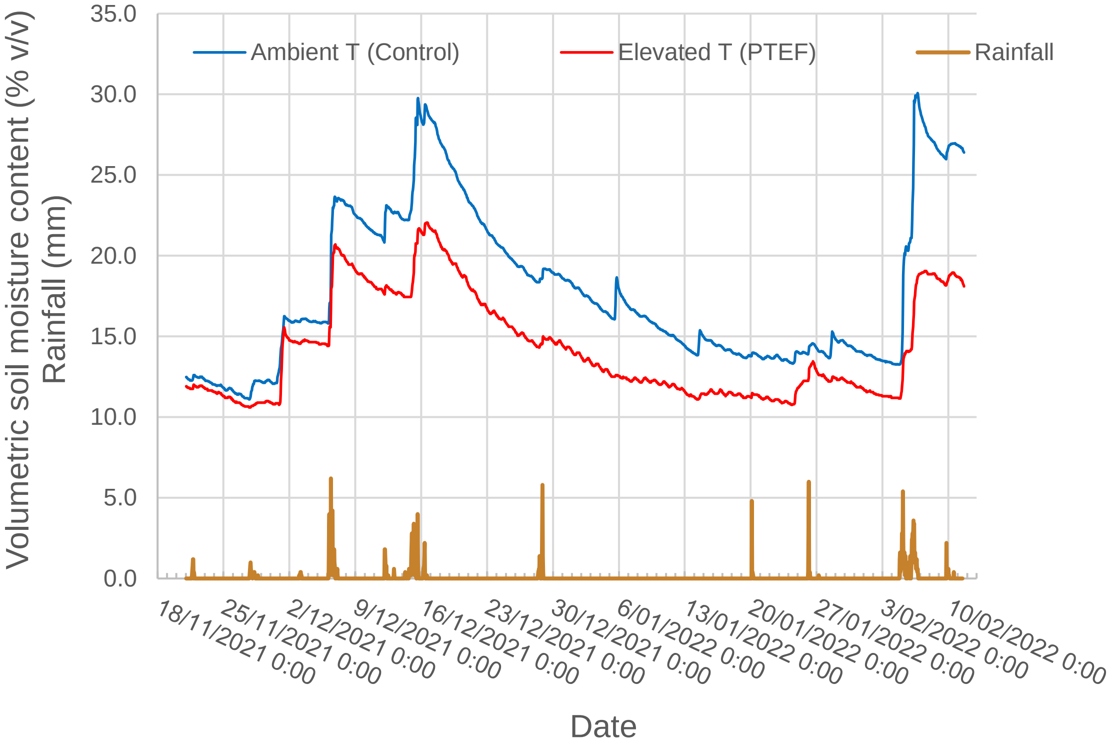

Figure 6**.** Volumetric soil water content (% v/v) integrated over 300 mm depth and within the vine row for control (mean of four sensors) and passive temperature elevation frame (PTEF) (mean of two sensors) treatments from 21 November 2021 to 12 February 2022 (1 week after PTEF treatment removed on 5 February 2022). Also shown are rainfall events measured in mm recorded at the Marlborough meteorological station 720 m from the trial site.

From mid-November 2021 to mid-February 2022 there was a highly significant (p<0.001) effect of the PTEF treatment, decreasing the mean volumetric soil moisture content in the top 300 mm of soil in the vine row to 14.0 %v/v compared with 17.1 %v/v for the ambient control treatment (Figure 6). This equates to a mean difference of 3.1 %v/v between treatments across the whole monitoring period. Respectively, for the control and PTEF treatments and for the same time period, minimum volumetric soil water contents were 11.1 and 10.6 %v/v, with maximum volumetric soil water contents of 29.8 and 22.1 %v/v. Initially from mid-November, treatment differences were not that great, but increased further as the season progressed. Of note is that absolute volumetric soil moisture content values changed in concert for both treatments, and typically both increased following rainfall events. That this occurred for the PTEF treatment despite the PTEF system footprint covering the soil surface immediately adjacent to vines and extending 1.4 m into the inter-row, suggests a significant amount of sub-surface lateral flow of water and/or significant capture of rainfall by the still exposed canopies.

3.2 Phenology: flowering

The PTEF (elevated T) treatment vines reached 50% flowering in both basal and apical inflorescences on average 5.25 days in advance of control (ambient T) vines (Figure 7). In both treatments, 50% flowering in basal inflorescences consistently occurred 2 days before apical inflorescences. At 18 days, flowering was 100% complete in PTEF-treated vines and 95% complete in control vines.

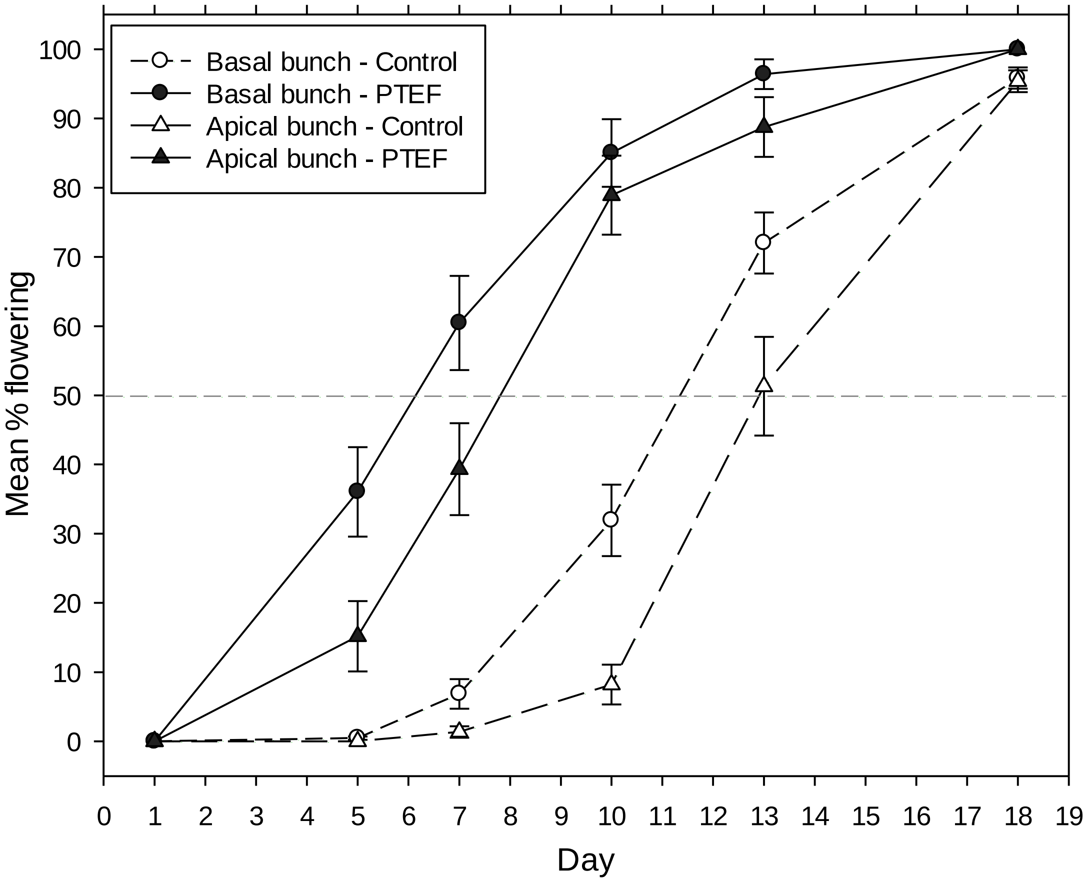

Figure 7. Mean percentage flowering of both basal and apical (where present) inflorescences on selected shoots of control (ambient T) and passive temperature elevation frame (PTEF) (elevated T) treatments as indicated in the key. Bars = 1 x standard error, n = 20. Dashed horizontal line indicates 50% flowering. Day 1 corresponds to 18 November 2021.

3.3 Phenology: véraison

For the mean berry softening (Figure 8), the mid-point of softening (equivalent to 50% véraison) was reached (p<0.001) in PTEF-treated vines, 9 days before control vines. There was a highly significant (p<0.001) effect of time on berry softening, plus a highly significant (p<0.001) time x treatment interaction, suggesting that treatments had different rates of berry softening.

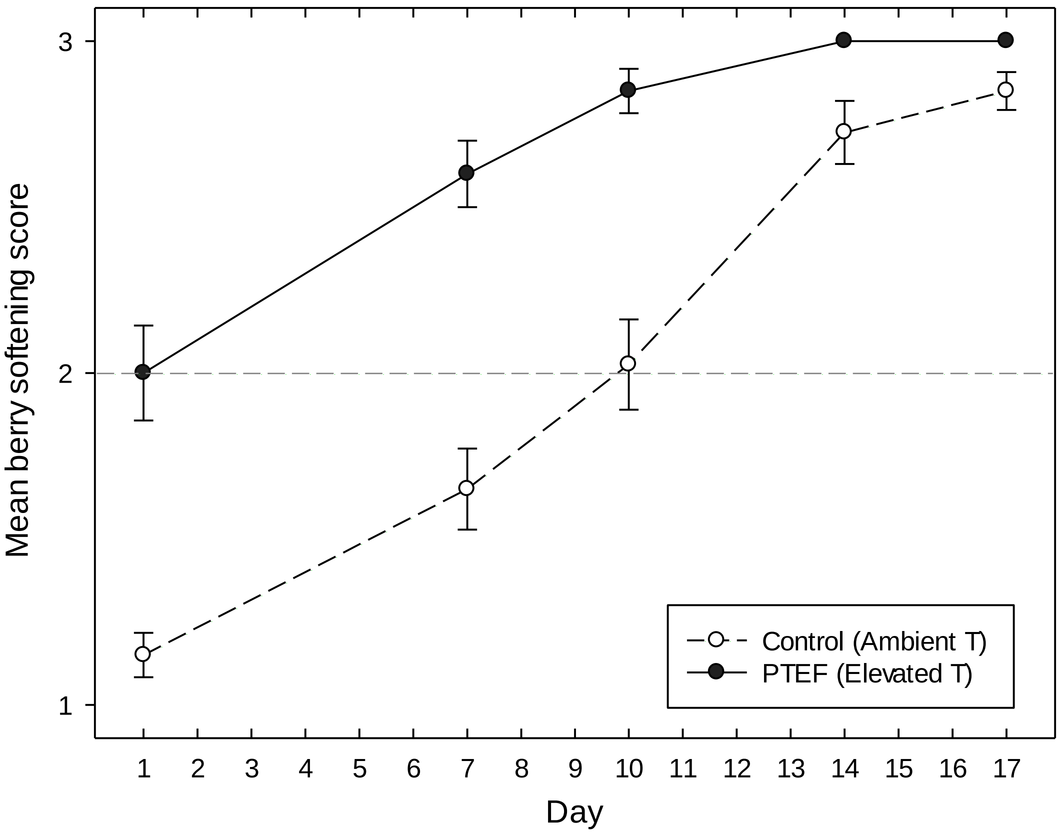

Figure 8. Mean berry softening score on randomly selected bunches of control (ambient T) and passive temperature elevation frame (PTEF) (elevated T) treatments as indicated in the key. Bars = 1 x standard error, n = 40. The dashed horizontal line indicates the mid-point of berry softening between hard (=1) and fully soft (=3), equivalent to 50% véraison. Day 1 corresponds to 8 February 2022.

3.4 Grape maturation

Mean berry total soluble solids accumulation was significantly (*p*<0.001) advanced in PTEF-treated vines compared with control (Figure 9), being 2.0 °Brix higher on the first measurement occasion (15 February 2022). This advantage decreased to 0.9 °Brix by day 36 (23 March 2022). There was a highly significant (*p*<0.001) effect of time on mean berry total soluble solids, but no significant time x treatment interaction, suggesting that the rate of total soluble solids accumulation in the two treatments were not different. Rainfall and a few days of overcast weather resulted in the harvest of PTEF-treated vines at day 49 (4 April 2022) achieving a harvest mean total soluble solids of 22.7 °Brix, only very slightly above target. Eight days later (12 April 2022) control treatment vines were harvested with a mean total soluble solids content of 23.1 °Brix, just 0.4 °Brix higher than the PTEF treatment and 0.6 °Brix above target.

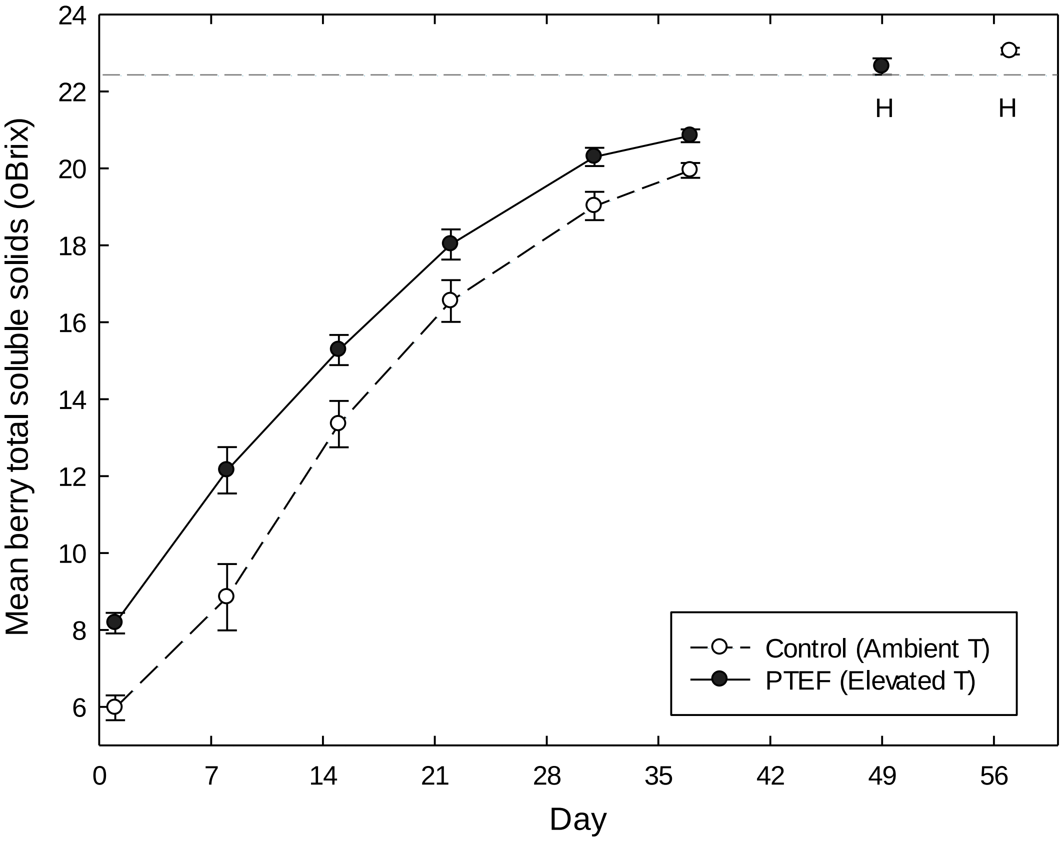

Figure 9. Mean berry total soluble solids (°Brix) of control (ambient T) and passive temperature elevation frame (PTEF) (elevated T) treatments as indicated in the key. Bars = 1 x standard error, n = 4. The dashed horizontal line indicates the total soluble solids target of 22.5 °Brix. Day 1 corresponds to 15 February 2022. H indicates date of harvest for each respective treatment.

4 Discussion

In line with the aims and objectives outlined in the introduction, we successfully design-modified, constructed and deployed a prototype in-vineyard system to passively heat developing grapevine bunch zones and canopies during the 2021–22 growing season. Data and results from temperature sensors located in the developing bunch zone demonstrated that the PTEF system successfully elevated temperature by an average 1.4°C over a 4-month period, to simulate future warmer growing conditions in Marlborough. To put that temperature elevation into context, the Intergovernmental Panel on Climate Change (IPCC) estimates that anthropogenic global warming is currently increasing at 0.2°C (likely between 0.1°C and 0.3°C) per decade due to past and ongoing emissions (IPCC 2018).

With the PTEF system being of passive warming design, on a diurnal basis (and perhaps not unsurprisingly) the majority of temperature warming in the developing bunch zone and canopy occurred during day time, with limited additional night-time warming (buffering) beyond a couple of hours past sundown. Nevertheless, we observed (and within 7 weeks from PTEF deployment) a 5-day advancement in phenology and the time to 50% flowering in warmer grown (PTEF) canopies compared with control. This was likewise followed by a 9-day advance in time to 50% berry softening (50% véraison), and advance in time to the start of total soluble solids accumulation and eventual harvest. Warmer growing season PTEF-treated vines were harvested 8 days earlier than control, although since control vines were harvested at a total soluble solids of 0.6 °Brix above target, a reasonable downward adjustment to 6 days difference between harvest dates may be more appropriate.

One possible caveat to the PTEF system approach we observed (beyond some routine logistical challenges to permit periodic tractor passes for vineyard management) were the observations of increased soil temperature and decreased soil volumetric water content within the PTEF footprint, albeit only assessed in the upper 300 mm soil profile. As well as more and potentially deeper soil profile monitoring to determine how significant these artefacts might be, there are also further practical solutions that could be considered and implemented in the future to control for these. Nevertheless, that these artefacts alone would be entirely responsible for the significant advance in various stages of phenology observed, seems unlikely.

Finally, we consider the PTEF system approach successfully developed here to be a valuable tool (rather than an absolute means to an end for climate change research), for advancing grapevine phenology development from bud-burst to mid-season. Had the PTEF been deployable pre bud-burst in 2021–22, we believe that we may have achieved an advance in phenology of up to 2 weeks by 50% véraison. In combination with other vine management approaches to advance or delay phenology, we believe we could achieve an advance total of possibly 4 weeks. A future aim would be to test this, but then once achieved, remove PTEFs. This would be so that mid- or post-véraison berry development could occur naturally (i.e. without any direct experimental treatment influence) under the prevailing ambient seasonal growing climate at the time. For example, early to mid-season PTEF treatment vine berry development might occur in warmer mid-summer, and control vine berry development in cooler late-summer/early-autumn, thereby providing clearly different climates for berry maturation, but at the same location during the same growing season.

5 Acknowledgements

We wish to acknowledge and are grateful for the financial support of the Marlborough Research Centre Trust for funding this project. We also wish to acknowledge and thank the support of Mr Glenn Kirkwood and Dr Stewart Field of the Nelson Marlborough Institute of Technology for use of their research vineyard, assistance with aspects of vineyard management, and helpful discussion.

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