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ASSESSMENT OF THE CARBON AND WATER BALANCES OF SAUVIGNON BLANC GRAPES USING EDDY COVARIANCE

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Abstract

Eddy covariance (EC) is an established technique for measuring gas flux over a surface, typically carbon dioxide and water vapour. Perennial horticultural systems have the potential to be a carbon sink to help mitigate climate change and EC is potentially a useful tool to quantify this effect. We are using the EC technique to continuously measure the net carbon and water flux in a commercial vineyard in the Hawke's Bay. This vineyard is conventionally managed and irrigated, and grows a range of red and white grape varieties. Our aims for this experiment are: (i) to characterise the seasonal variation in carbon and water fluxes; and (ii) to quantify the annual carbon and water balances for a vineyard system.

We are operating two EC towers over a Merlot and a Sauvignon blanc block, respectively, and have been collecting data since 1 May 2019; however, the tower over the Merlot block has suffered an equipment failure and is not currently collecting flux data. Data are processed using standard EC methodologies.

Preliminary results suggest that over the early growing season, the magnitudes of both the carbon and water fluxes have been increasing and that the vines have been a strong carbon sink. Our results suggest that between 1 May 2019 and 8 February 2020 the vines have sequestered approximately 300 g C/m^2 of carbon and lost approximately 500 mm of water due to evapotranspiration.

While we do not have a full year of data collected, our results appear realistic compared with previous studies. The effects of various vineyard management practices and especially harvest on the seasonal and annual carbon and water balances are not yet known. We hope to be able to better answer these questions once an entire year of data are collected. Additionally, we plan to continue running the experiment for multiple years in order to explore the interannual variation, if any, in the carbon and water balances in the vineyard.

Introduction

Wine grapes are a major horticultural crop for New Zealand, with 297 million litres of wine produced and 269 million litres exported in 2019 (FAOSTAT 2020). Vineyards occupy approximately 39,000 ha of land in New Zealand, concentrated around Marlborough and the Hawke's Bay (New Zealand Winegrowers 2019).

Perennial horticulture has often been suggested as a potential carbon sink to help mitigate the effects of climate change as carbon can be sequestered in both the plants and soil (Kroodsma and Field 2006). However, vineyard management and wine making are sources of carbon emissions and have the potential to reduce or even reverse the positive effects of carbon sequestration of the grape vines (Chiriaco et al. 2019). The analysis of the carbon footprint of the entire cycle of wine production is outside the scope of this study, rather we are interested in the carbon budget of the wine grapes themselves as they are growing. In particular, we are interested in quantifying the net carbon budget of the vineyard and how it relates to (a) the absorption and sequestration of carbon by the grapes, and (b) the carbon emissions related to vineyard management.

Eddy covariance (EC) is the technique chosen to measure the carbon fluxes of the vineyard (Burba 2013). EC is an established and defensible method for measuring gas flux over a surface; however, there are few studies using EC to measure carbon fluxes of horticultural systems and none in New Zealand. Most studies using EC have been over relatively stable systems such as forests and grasslands for two main reasons. Firstly, standard EC methodology assumes that the area being observed is relatively large, flat and homogenous, and horticultural systems often do not satisfy all these conditions. Secondly, it is difficult to account for the effects of horticultural management on the resultant fluxes. Various management practices such as spraying, pruning and harvest can all produce carbon fluxes that are potentially difficult to quantify, both in terms of isolated fluxes and total carbon budget.

Since EC instrumentation will also provide water vapour fluxes, we take the opportunity to assess the water loss from the grape vines due to evapotranspiration (ET). This is not a main objective of our study, although the water loss from ET can help give context to our carbon measurements.

Site description

Our study is located on a conventionally managed, commercial vineyard in the Hawke's Bay. The region has a mean annual temperature of 14.0°C, mean annual precipitation of 707 mm and fluvial soils. The vineyard produces a range of varietals; however, the towers we operate are measuring a block of Merlot and a block of Sauvignon blanc that is currently being changed over to Pinot gris.

The general management of the vineyard is typical for New Zealand. Harvest typically occurs in mid-March, followed by cane pruning to prepare the vines for the next year's growth. Sheep are grazed in the vineyard over the winter. The vines generally start to bud in early October and flower in early December. During the growing season, the underrow is sprayed and mechanical pruning is performed. The vines are drip irrigated. The Merlot block observed is approximately 18 ha and the Sauvignon blanc block is approximately 9 ha, both with 2000 plants per hectare. Yields average approximately 20 tonnes per hectare. Beginning in December 2019, the Sauvignon blanc grapes were changed over to Pinot gris, and this was done by cutting the canes off at the rootstock and grafting Pinot gris scions there.

Eddy covariance towers

We are operating two EC towers, approximately 2 km apart. They have been running continuously since April 2019 and preliminary results from 1 May 2019 to 8 February 2020 are presented here.

One tower is observing a Merlot block (Figure *1*a). Its main EC sensors are at 5 m height, giving an approximate flux footprint of 300 to 400 m depending on current canopy height. It has a typical loadout of ancillary meteorological and soil sensors (Table 1). The soil sensors are located in the row beside the tower, at the edge of the block. In May 2019, the sonic anemometer on this tower failed so it is not performing flux measurements. We do not include flux measurements from this tower in this study; however, the ancillary measurements are potentially useful.

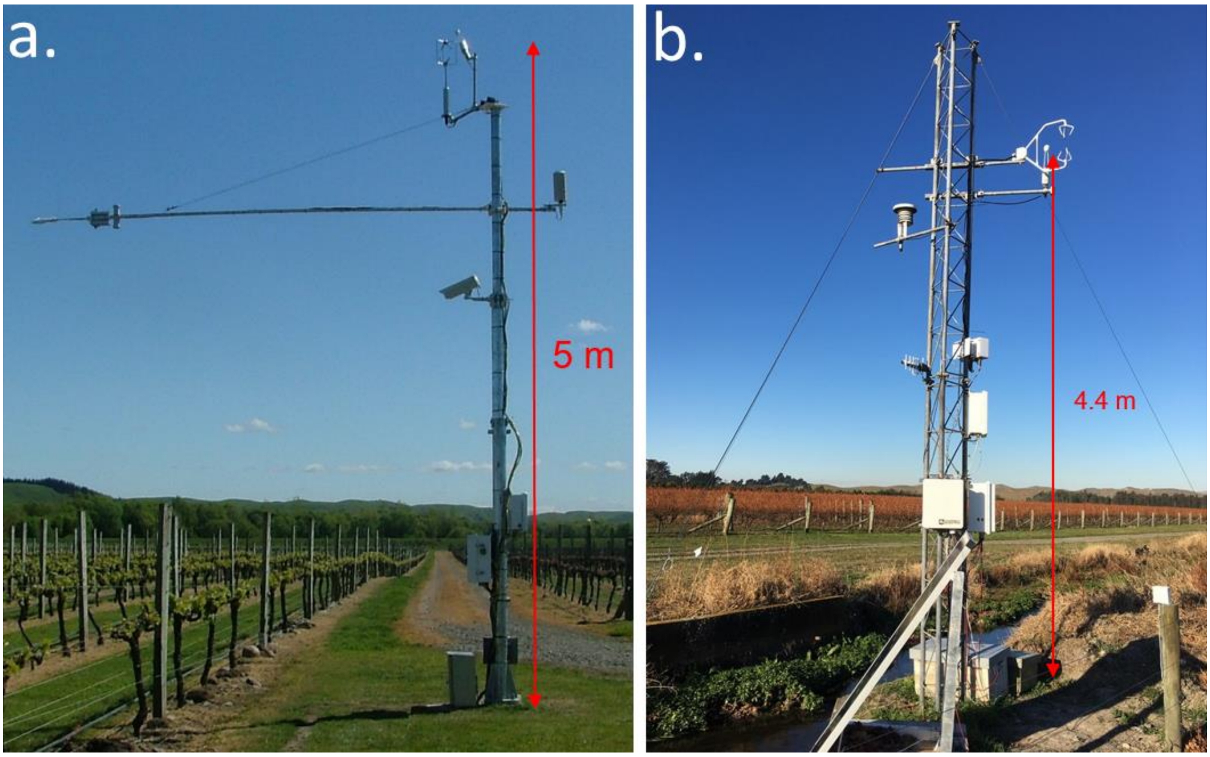


Figure 1: The Merlot eddy covariance (EC) tower (a) and the Sauvignon blanc EC tower (b). Heights of the main EC sensors are marked.

The other tower is observing a Sauvignon blanc block (Figure *1*b). Its main EC sensors are at 4.4 m height giving an approximate flux footprint of 240 to 340 m, depending on current canopy height. It too has a typical loadout of meteorological and soil sensors (Table 1); however, it does not have a net radiometer. This is because, due to requirements for vineyard operation, we were not able to locate the tower close enough to the grapes to be able to mount a net radiometer above them. We assume that the measurements from the net radiometer over the Merlot block are also valid for the Sauvignon blanc block. The towers are located close to each other and the net radiation measurements are half-hour averages, so short-term variations are assumed not to affect the measurements. We also assume there is little difference in the reflective properties of Merlot and Sauvignon blanc vines. While the meteorological sensors (wind, temperature, relative humidity, precipitation) on this tower are located on or beside the tower, the soil sensors are located approximately 100 m away in the middle of the vine block. Both towers are equipped with modems to allow remote data collection.

Eddy covariance methodology

EC is an established method of measuring the gas flux over a surface of interest, typically carbon dioxide or water vapour. The core instruments are a three-dimensional ultrasonic anemometer and a gas analyser. By comparing how the gas concentration changes with respect to the vertical wind, the amount of gas either absorbed by or emitted from a surface can be measured. The usual convention is to indicate gas emission with positive fluxes and gas absorption with negative fluxes, and that is done here.

Table 1: Instrument loadouts of the two eddy covariance (EC) towers

	Merlot tower	Sauvignon blanc tower
Height	5 m	4.4 m
Footprint	300~400 m	240~340 m
Anemometer	Gill Windmaster Pro	Campbell Scientific CSAT3
Gas analyser	Licor 7500A	Licor 7500
Temperature and relative humidity	Vaisala HMP155	Vaisala HMP60
Ancillary wind	n/a	NRG 40H cup anemometer W200P windvane
Precipitation	n/a	Rain-o-Matic small
Leaf wetness	Decagon	n/a
Net radiation	Kipp & Zonen CNR4	n/a
PAR	Licor LI-190	n/a
NDVI	Skye 1860	n/a
Soil temperature	TCAV thermocouple	Tranzflo thermocouple
Soil heat flux	Huskeflux HFP01	REBS HFT-3.1
Soil water content	Delta-T ML300	Campbell Scientific CS616
Datalogger	Sutron	Campbell Scientific CR1000

Standard EC practices are followed in this study. Raw wind and gas measurements are taken at 10 Hz and resultant fluxes are calculated over half-hour periods. The software used for flux calculation is EddyPro v7.0.4, further analysis is done in R. Basic quality control is done with the steady state and well-developed turbulence tests, using the 0-1-2 system of Mauder and Foken (2006). Only high-quality fluxes are presented here. One-dimensional flux footprints are estimated using the method of Kljun et al. (2004). Physically unrealistic results are filtered out. Since these results are preliminary, effects on the fluxes from the management of the vineyard have not been considered yet.

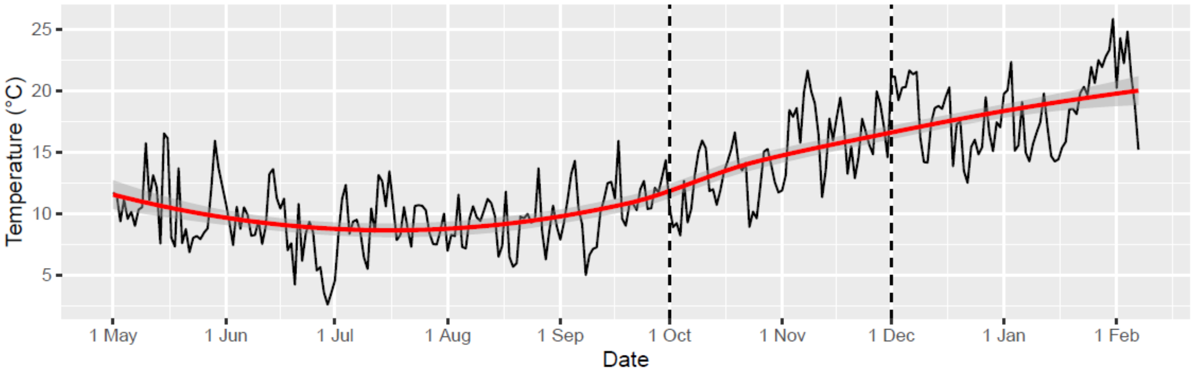
In addition to the gas fluxes, several ancillary measurements of various meteorological and soil properties are taken. These provide context to help interpret any effects the local weather and soil conditions may have on the fluxes.

Results

Preliminary results for the first 9 months of data are presented here. While we are confident in the fluxes presented here, any interpretation of the fluxes in terms of partitioning must be done with care.

Figure 2 shows the mean daily air temperature (A) and the cumulative rainfall (B) for the 9 months that the towers have been operational. So far, the year has appeared typical, with a mean temperature of 12.8°C and 412 mm of rain over 9 months. The approximate dates of 50% budbreak (1 October) and 50% flowering (1 December) have been marked as they are important milestones in the development of a crop.

A. Mean daily air temperature



B. Cumulative rainfall

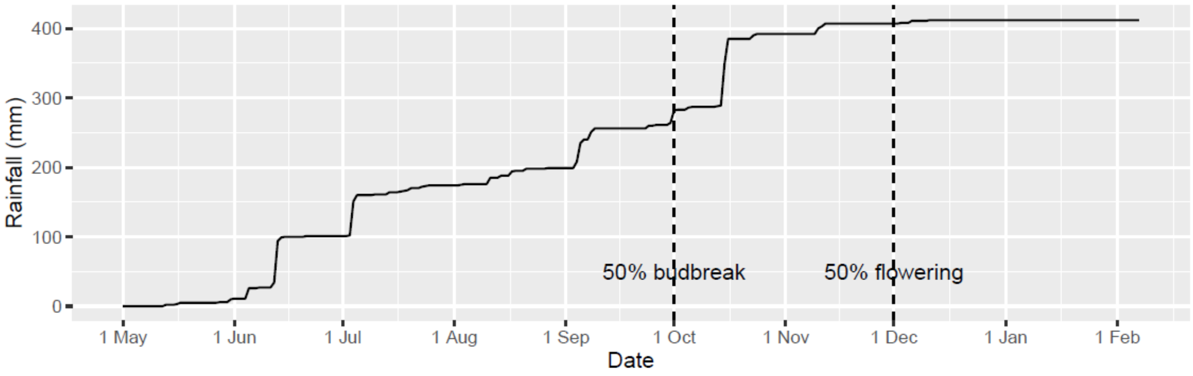


Figure 2: (A) mean daily air temperature and (B) cumulative rainfall in the vineyard since the towers were operational.

Figure 3 shows the daily patterns of flux for carbon and water vapour, typical of EC measurements. There is little activity during the night because of calm and stable atmospheric conditions, and in the day there are consistent large fluxes due to photosynthesis and heating from the sun, peaking when the sun is at zenith. The data in Figure 3 are averaged by month so we can see the seasonal patterns in the fluxes. As expected, the fluxes are relatively small in the winter months and steadily increase during the spring and early summer. However, the fluxes then decrease over the late summer, with the magnitude of the carbon fluxes decreasing more than the water fluxes. As shown in Figure 4, we believe that the decrease in flux magnitude is likely because of the changeover from Sauvignon blanc (a) to Pinot gris (b) in December 2019 and January 2020. This involved cutting the Sauvignon blanc canes right back to the rootstock and replacing with Pinot gris scions, drastically reducing the amount of plant material available for photosynthesis. This could also explain the greater decrease in carbon fluxes compared with water fluxes since photosynthesis is the main driver for carbon absorption but not for evapotranspiration. While plant respiration is a factor in ET, water can also be evaporated from the soil due to heat from the sun. The vines are irrigated during the growing season and this provides another source of water for which evaporation can occur.

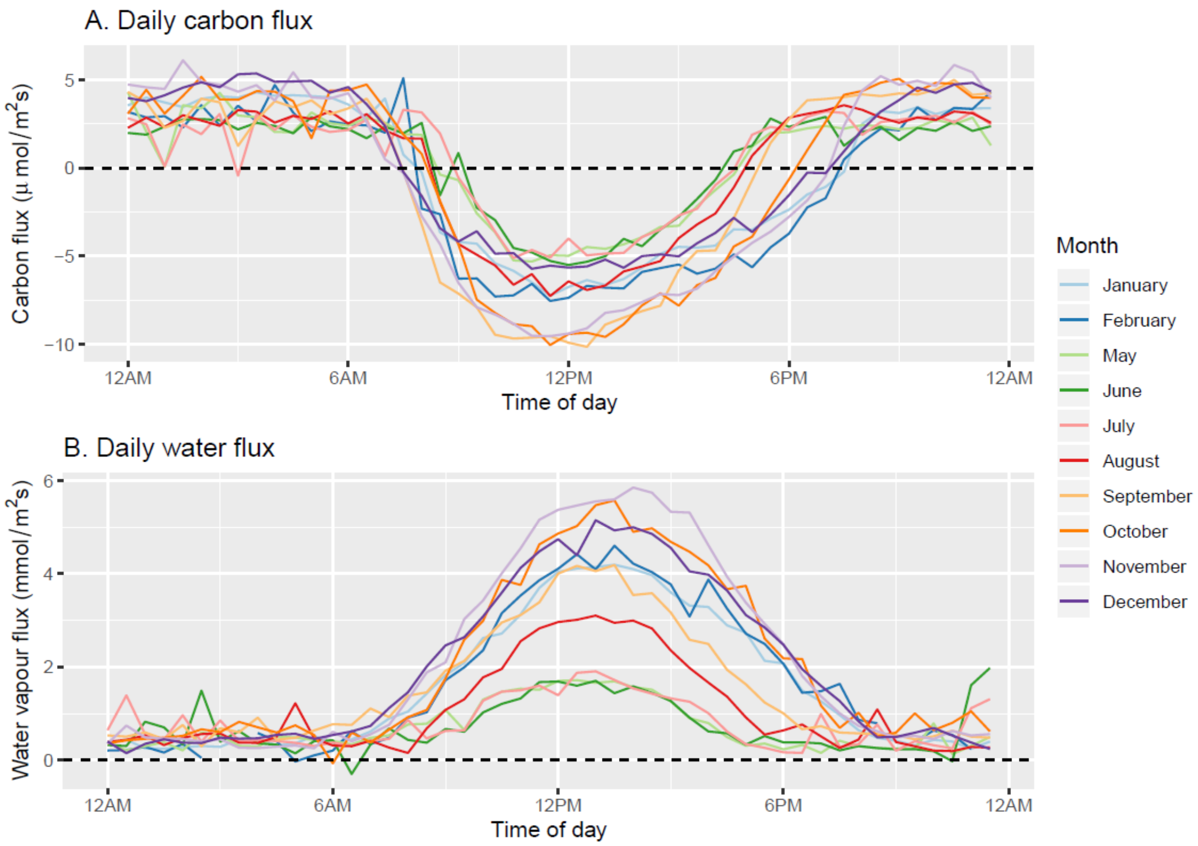


Figure 3: Daily patterns of flux for (A) carbon and (B) water vapour. Data are averaged by month.

Figure 4: Comparison of the vines in (a) March 2019 and (b) January 2020, showing the significant change in canopy coverage due to the switch from Sauvignon blanc to Pinot gris.

We are also interested in the cumulative carbon and water fluxes. These are derived by summing the net daily fluxes over time and are shown in Figure 5 (carbon) and Figure 6 (water). For each figure, (A) shows the net flux for each day and (B) shows the cumulative sum of the fluxes. As in Figure 2, 1 October and 1 December are marked as the approximate dates of 50% budbreak and 50% flowering. We see similar patterns to Figure 3, with relatively low net fluxes in the winter, increasing in the spring and summer. We also see a levelling off of carbon fluxes in December and January consistent with Figure 3.

Table 2: Monthly net fluxes for carbon and water vapour

	Month	Net carbon flux (g C/m^2)	Net water flux (mm)
2019	May	-19.3	19.7
	June	-13.8	18.0
	July	-11.5	20.7
	August	-24.9	36.9
	September	-44.2	50.4
	October	-48.2	74.9
	November	-64.8	88.2
	December	-25.8	101.0
2020	January	-37.4	64.8
	February*	-19.7	19.4
Total		-309.4	494.2

* Sums for February are only from 1 February to 8 February

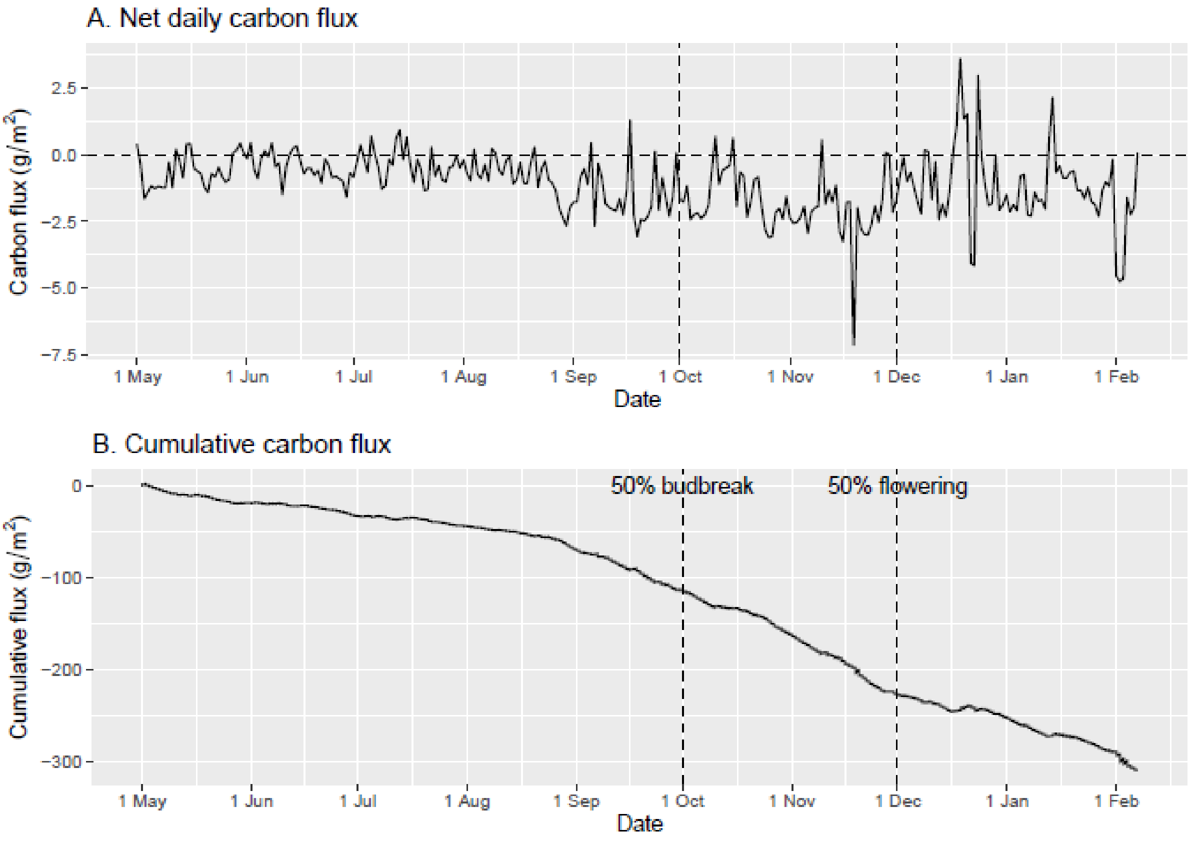


Figure 5: Net daily (A) and cumulative (B) carbon flux.

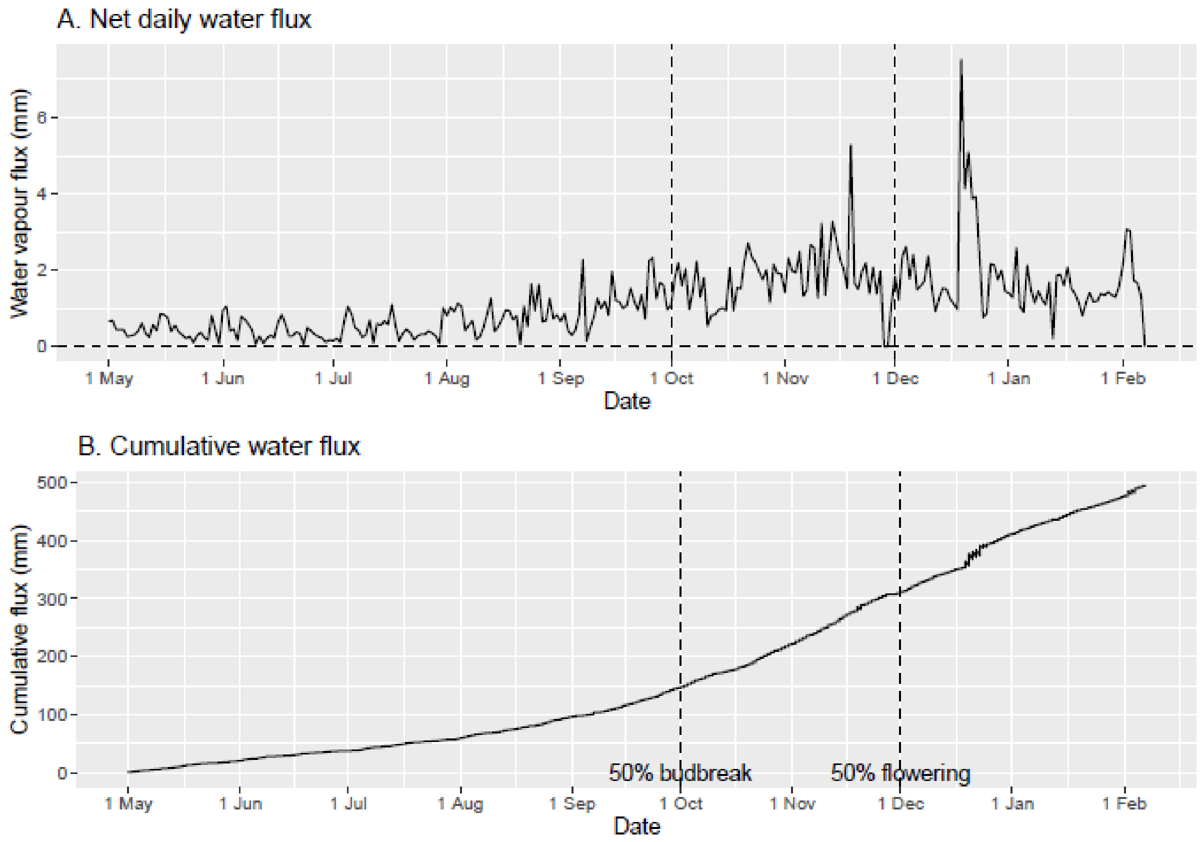


Figure 6: Net daily (A) and cumulative (B) water vapour flux.

We are also interested in the seasonal variations of fluxes, and Table 2 shows the monthly net fluxes, obtained by summing all the fluxes for each half-hour period over the entire month. While there are individual days of net positive carbon flux (emission, Figure *5*), on a monthly scale we always observed net absorption, from a minimum of 11.5 g C/m^2 absorbed in July to a maximum of 64.8 g C/m^2 absorbed in November. Again, we also see a drop in flux in December and January likely because of the changeover from Sauvignon blanc to Pinot gris. Similar patterns are seen in the water vapour fluxes, with a minimum of 18.0 mm of water lost because of ET in June and a maximum of 101.0 mm lost in December.

Discussion and future work

Even though these results are preliminary, we can compare them with other published results to determine whether our values seem reasonable. While no previous EC studies on New Zealand vineyards exist, work has been done on vineyards overseas. Studies of vineyards in Italy report average annual carbon uptakes of 134 g C/m^2 (Vendrame et al. 2019), 195 g C/m^2 (Marras et al. 2015), 150 g C/m^2 (Chiriaco et al. 2019) and 800 g C/m^2 (Pitacco and Meggio 2015). A study of a vineyard in China reports an average annual carbon uptake of 858 g C/m^2 (Guo et al. 2014). This is a rather large range of values; however, one key commonality in these studies is that all sites experience large interannual variations, for example Vendrame et al. (2019) reports between 69 g C/m^2 and 207 g C/m^2 absorbed per year and Guo et al. (2014) reports between 820 g C/m^2 and 961 g C/m^2 absorbed per year. Our preliminary carbon uptake value so far of 309 g C/m^2 would therefore seem realistic compared with these studies; however, we would like to collect several years of data to assess how variable our values are.

Seasonal variations are important to examine too. Several studies have reported similar seasonal patterns to what we observe, namely that net carbon flux is small and sometimes positive in the winter and increasing in the spring and summer. For example, Marras et al. (2015) report varying carbon fluxes of 20 to 40 g C/m^2 per month emitted during the winter and up to 108 g C/m^2 per month absorbed in the summer. Chiriaco et al. (2019) report net carbon emission in the autumn (October to December) of between 3.8 and 13.6 g C/m^2 per month and net absorption throughout the rest of the year, with the greatest absorption being 43.1 g C/m^2 in July. Our results show that while there are individual days with net positive carbon fluxes (emission), the monthly fluxes always show net absorption; however, the amount absorbed is far lower in the winter than in the summer. Similar to the annual carbon balances, other studies show large variations in results, and we consider our preliminary values to be realistic.

In terms of water vapour flux from ET, studies of agricultural systems in New Zealand report annual ET values of 791 mm for pasture and 829 mm for ryegrass (Graham et al. 2016), 817 mm for pasture (Kirschbaum et al. 2015) and 768 mm for pasture (Pronger et al. 2016). Our results are somewhat lower than this (494 mm) but we only have 9 months of data. Extrapolating the current cumulative ET to 1 year gives us approximately 650 mm ET, but that is likely to be revised once we have an entire year's data. None of these studies have been on perennial horticulture, however, so even though our numbers are comparable, these comparisons are potentially of limited use. Li et al. (2015) performed a study of water use efficiency on a vineyard in northern China over 5 months. While they could not report annual ET, their diurnal patterns of water flux were similar to our results, with a peak water flux of approximately 6 mmol/m^{2}s in the middle of the day in late summer. Like the carbon fluxes, our water fluxes are similar to other reported values so we consider them realistic.

Future work

Since our results are quite preliminary there is plenty of work still to do. The first step is to collect an entire year's worth of data, in particular data around harvest time, to have a better idea of both the seasonal variations and annual balances of carbon and water fluxes. Since EC is an inherently 'gappy' process and we have several missing days of data, we would also need to perform further quality control and gap filling to produce accurate annual and seasonal fluxes. We also aim to quantify the influence of vineyard management on the carbon and water fluxes, which includes, but is not limited to: harvest, pruning, spraying and sheep grazing. We would also like to continue data collection for several years so we are able to examine the interannual variation in the net carbon and water fluxes.

Conclusions

We installed an EC system on a vineyard in the Hawke's Bay in April 2019 and we present our preliminary results from 1 May 2019 to 8 February 2020. The main aims of the experiment are to quantify the net carbon and water balances of Sauvignon blanc grapes in terms of the seasonal variations and annual balances. While our results are preliminary, they appear realistic compared with other similar studies so we have confidence in them so far. However, we require at least 1 year's worth of data and additional work accounting for the various vineyard management practices in order to confirm our results.

Acknowledgements

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