Sap Flow Sensors and Irrigation Management

Dr. Michael Forster

Director, Implexx Sense

Adjunct Senior Research Fellow, Griffith University, Australia

Sap flow is the water flow within grapevines, and it is essentially equivalent to total vine water use or transpiration. Sap flow sensors (Figure 1) are a useful tool for irrigation management because they can provide precision data on vine water demand (litres or mm per vine or hectare) as well as irrigation timing. Sap flow sensors allow seasonal adjustments to irrigation whether the grapevine is in growth, flowering or véraison. This article introduces sap flow data and how sap flow sensors can quantify total vine water demand and irrigation timing.

Figure 1. The Implexx Sap Flow Sensor, installed here on a grapevine, measures sap flow, water use or transpiration.

A weekly pattern of sap flow

During the 2019/2020 growing season, sap flow was measured on Shiraz and Chardonnay grapevines at the NSW Department of Primary Industries Griffith Research Station. An example data set of sap flow is presented in Figure 2. These data were of 7 days during the first week of November 2019.

Sap flow is minimal during the night and increases to a peak around solar noon. Sap flow is higher on hotter, drier days and lower on cloudy or rainy days. Sap flow can also be relatively high during the night when air temperature is high and relative humidity is low.

Sap flow will vary between vines and varieties. For example, Figure 2 shows sap flow in a Shiraz grapevine had a peak around 0.7 litres per hour whereas a Chardonnay vine, at the same location, peaked around 0.4 litres per hour. The differences between vines and varieties are due to numerous factors. In this case, however, the Shiraz canopy, or total leaf area, was almost twice as large as the Chardonnay so it was a bigger vine with more water demand.

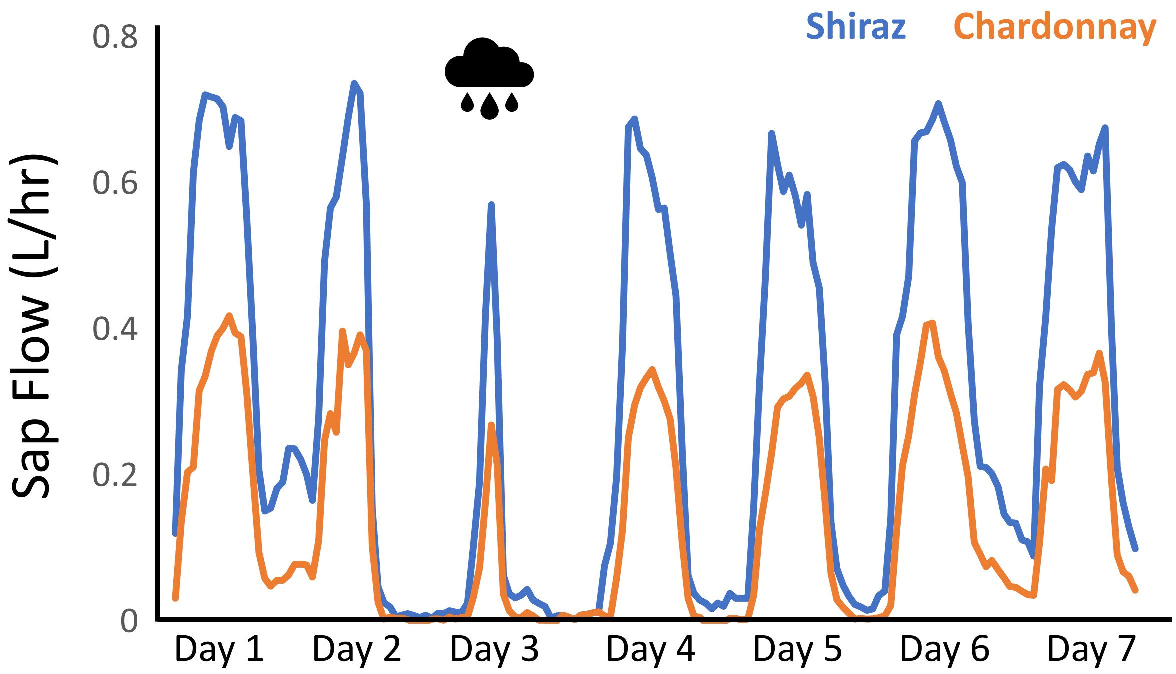

Figure 2. An example 7-day data set of sap flow data (litres per hour) from Shiraz (blue line) and Chardonnay (orange line) vines during the first week of November, 2019, from NSW Department of Primary Industries Griffith Research Station. Day 3 was a rainy day.

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Total vine water demand

The most important information a sap flow sensor can provide is the total vine water use (litres of water per hour or per day). Understanding the actual amount of grapevine water demand is critical for efficient use of water resources and irrigation management. With knowledge of water output from a vineyard, it is possible for sap flow sensors to improve vineyard water use efficiency and potentially lower irrigation costs.

Figure 3 presents the same data from Figure 2 but expressed as litres per day. Excluding the rainy day on Day 3, sap flow per day ranged between 6 and 12 litres for Shiraz and 4 to 6 litres for Chardonnay. The total daily sap flow will vary according to weather conditions, but these values provide an insight into how much water an individual vine requires.

Generally, grapevine water use is approximately 5 to 20 litres per day, but these numbers can vary according to season, time of year, variety, weather conditions, and other factors. For context, water use for a 4m tall apple tree is around 20 litres per day, a 6m tall pear tree is approximately 100 litres per day, and water use in the largest trees in the world, the Californian redwoods (*Sequoia sempervirens*), is approximately 2000 litres per day!

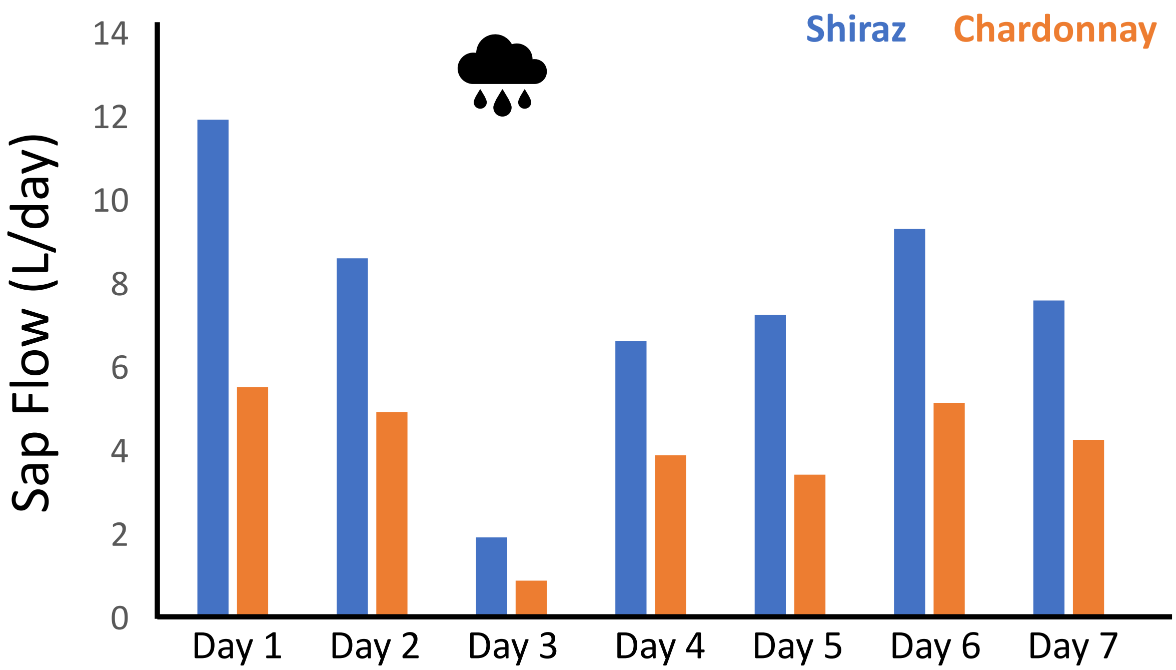

Figure 3. Total daily vine sap flow (litres per day) for the same Shiraz (blue bars) and Chardonnay (orange bars) presented in Figure 2.

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Vine transpiration and sap flow sensors

Sap flow can be divided by total leaf area to give transpiration (mm per hour or per day). Figure 4 is the transpiration of Shiraz and Chardonnay (i.e. the sap flow data presented in Figure 2 divided by total leaf area). The difference between Shiraz and Chardonnay total vine sap flow, seen in Figure 2, was caused by the Shiraz vine having a larger total canopy leaf area than the Chardonnay vine. Transpiration of the vines is similar once canopy size has been considered.

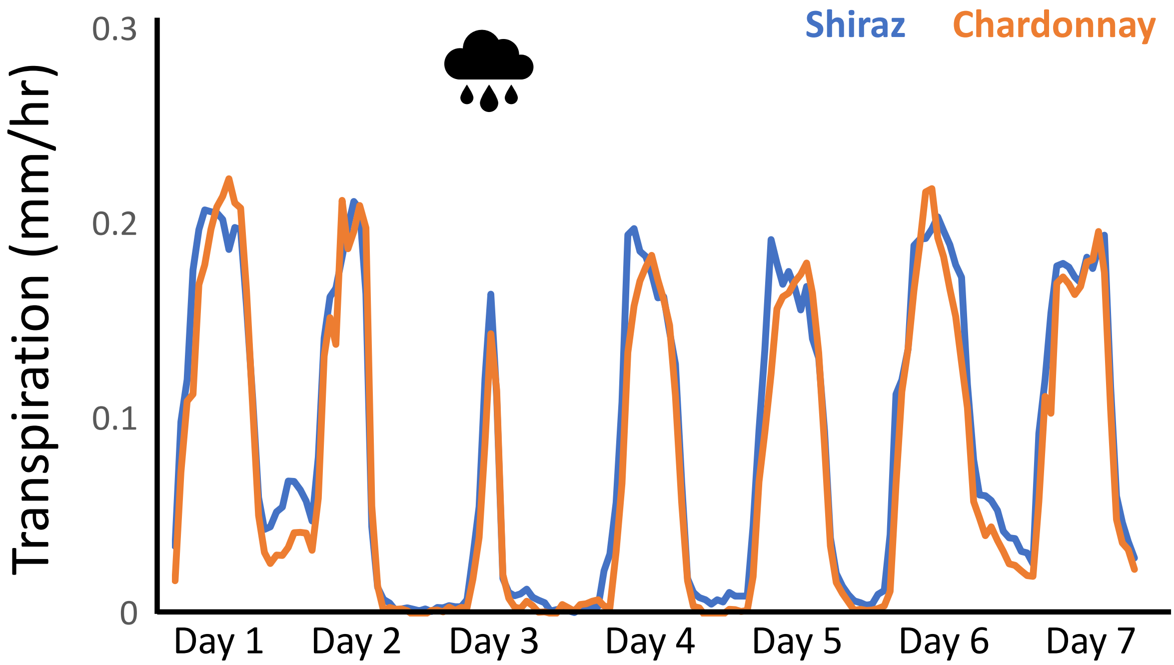

Figure 4. Transpiration (mm per hour) can be easily calculated by dividing total vine sap flow by total vine leaf or canopy area. The Shiraz (blue line) and Chardonnay (orange line) transpiration is similar indicating differences in sap flow, shown in Figure 2 and 3, were due to the Shiraz having a larger leaf area/canopy than the Chardonnay vine.

Grapevine transpiration can be directly compared against evapotranspiration measured via a weather station (Figure 5). Evapotranspiration, also known as potential evapotranspiration (ETo), was calculated via the Penman-Monteith (PM FAO-56) method. Actual transpiration of the grapevine can be modelled by including total vine leaf area or canopy area in a modified PM FAO-56 model. This is also known as a type of crop factor which is presented in Figure 5 as Penman-Monteith ETc. The sap flow or transpiration data measured from the grapevine should be equal (or similar) to the ETc value. This is demonstrated in Figure 5 where Shiraz and Chardonnay ETc is similar to Penman-Monteith ETc.

From Figure 5, total vine water demand for the Shiraz and Chardonnay vines, growing in Griffith during early November 2019, was approximately 3 mm per day. Note that actual vine transpiration is 2 to 3 times lower than ETo. Therefore, if irrigation management was based only on a regional weather station's ETo values, then the amount of irrigation may be 2 to 3 times more than is required by the vines. In this example, an irrigation decision based only on ETo may lead to over irrigation. Instead, irrigation decisions should be based on ETc.

In theory, irrigation can simply replace the amount of water that was transpired by the grapevine. In this example, in Griffith during the first week of November, that is around 3 mm per day per vine. However, in practice, one drop of water does not necessarily replace one drop of sap flow. There are other factors to consider, such as leaky pipes/valves, surface run-off, drainage, and so on. Therefore, an additional amount, such as an additional 10 or 20 percent, should be added to total irrigation.

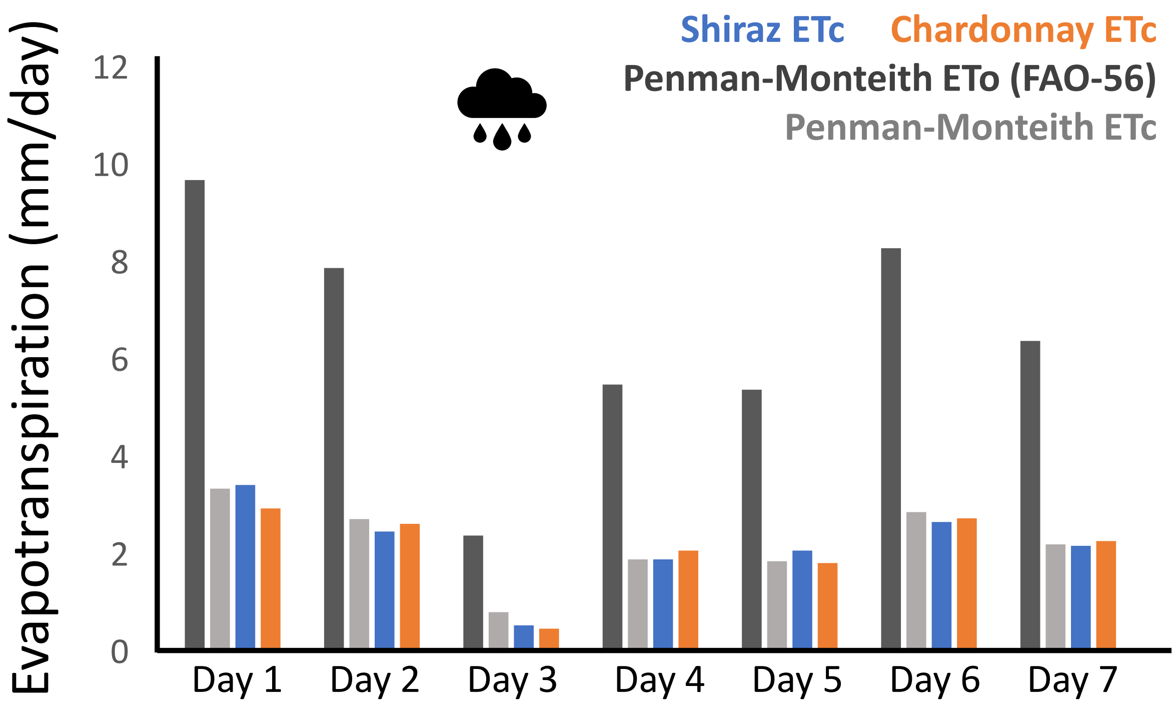

Figure 5. A 7-day comparison of potential evapotranspiration (Penman-Monteith ETo FAO-56) versus a model crop evapotranspiration (Penman-Monteith ETc) and Shiraz and Chardonnay transpiration. In theory, Shiraz and Chardonnay ETc should equal model, Penman-Monteith ETc as can be seen in this figure.

Irrigation scheduling or timing

Irrigating according to the plant's requirements is a more efficient use of water resources. In this regard, sap flow sensors can be used to determine irrigation scheduling.

The simplest approach is to periodically replace the daily water demand, or transpiration, from the grapevine. For example, if the daily data from Figure 4 are summed for the 7-day period, then the measured Shiraz grapevine water demand was approximately 50 litres. An irrigation strategy will then irrigate around 50 litres of water per Shiraz vine once per week or 25 litres twice per week. This is a simple irrigation strategy that can work very well. However, sap flow sensors can also be used for more precision irrigation strategies.

When there is ample soil moisture, grapevine transpiration will equal crop evapotranspiration as shown in Figure 5. As soil moisture decreases, grapevine transpiration will also decrease relative to crop evapotranspiration. This pattern indicates that the vine is experiencing mild water stress. At this point, irrigation should commence.

Figure 6 shows a two-week period of soil moisture (measured at 200 mm soil depth with a TEROS-11 Soil Water and Temperature Sensor), Shiraz and Chardonnay transpiration (ETc), and Penman-Monteith crop evapotranspiration (PM ETc). The data were collected between November 8th and 21st, 2019, from the NSW Department of Primary Industries Griffith Research Station. The vines received irrigation on Day 1 and there was no subsequent irrigation or rainfall over the two-week period presented in Figure 6.

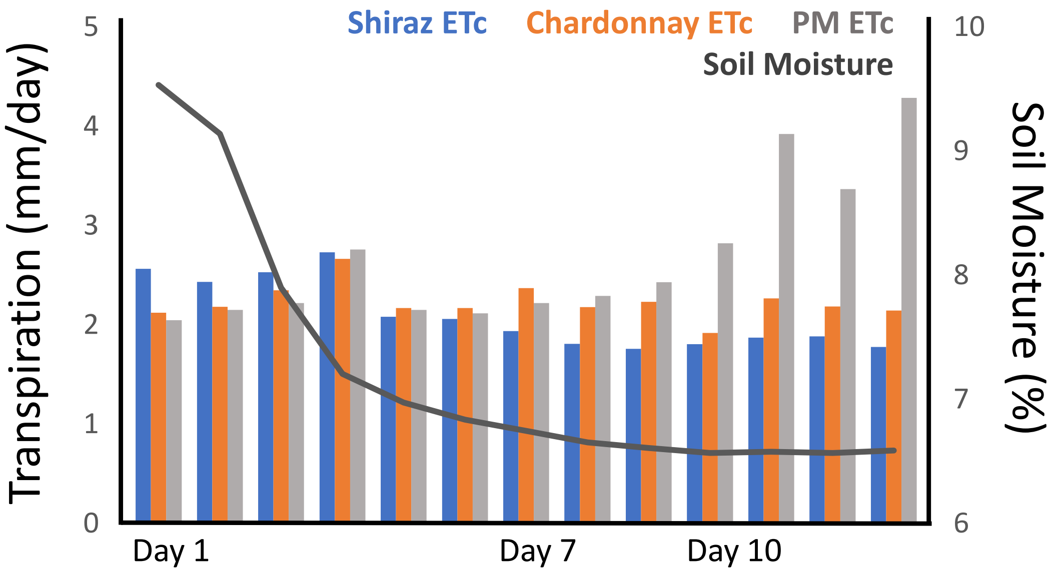

Figure 6. A two-week dry-down period where irrigation was only applied on Day 1. Soil water volumetric content (%, black line), at 200mm depth, decreased over the period. Shiraz (blue bars) and Chardonnay (orange bars) transpiration was compared against crop evapotranspiration (PM ETc, grey bars) from a weather station.

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At the start of the period, Shiraz and Chardonnay ETc equalled, or was slightly greater than, PM ETc. This pattern indicates that the measured grapevines had access to ample soil moisture and were under no water stress.

From approximately Day 7 and Day 8, Shiraz and Chardonnay ETc decreased relative to PM ETc. Such a pattern indicates that vines are starting to experience mild water stress.

Towards the end of the two-week period, Shiraz and Chardonnay ETc were substantially lower than PM ETc. This pattern indicates that vines are experiencing water stress. Therefore, the results from Figure 6 suggest that irrigation should have commenced around Day 7 or 8 for these measured vines.

Transpiration ratio and irrigation timing

The Transpiration Ratio is a value that indicates when irrigation should commence. The Transpiration Ratio is grapevine transpiration divided by the weather station PM ETc. Irrigation should commence when the Transpiration Ratio decreases below a critical threshold.

Figure 7 displays the Transpiration Ratio for the same data presented in Figure 6. When the Transpiration Ratio is 1, then grapevine ETc and PM ETc are equal. When the Transpiration Ratio decreases, then this indicates vine water stress. The smaller the Transpiration Ratio, then the greater the water stress in the grapevine.

Irrigation timing can be based on the Transpiration Ratio where irrigation should start when the Transpiration Ratio is less than 1. A Transpiration Ratio of 0.95 is a conservative strategy whereas a Transpiration Ratio of 0.9 may be more optimal. In Figure 7, the red dashed line indicates when the Transpiration Ratio is 0.9. From this evaluation, Shiraz irrigation should have commenced from Day 7 whereas Chardonnay irrigation should have commenced from Day 10.

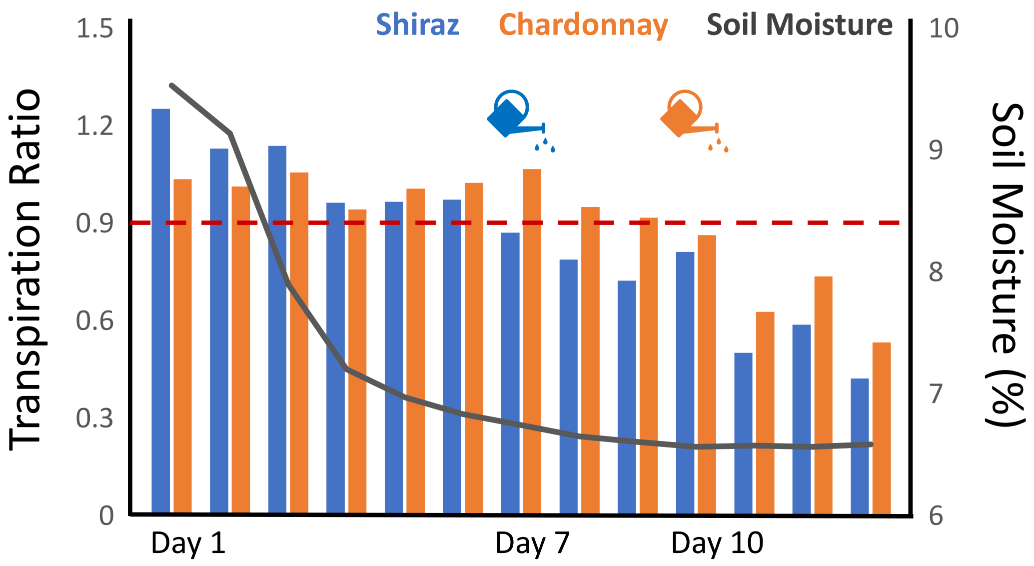

Figure 7. The Transpiration Ratio indicates when irrigation should commence. The red dashed line is a Transpiration Ratio of 0.9. When grapevine Transpiration is below the red dashed line, irrigation should commence. In this example, Shiraz irrigation should have commenced on Day 7 and Chardonnay on Day 10.

Conclusion

Sap flow sensors directly measure grapevine water use. Total vine sap flow can be converted to transpiration by dividing sap flow by total leaf area. Sap flow or transpiration values can be used to determine vine water demand. The amount of irrigation can replenish the amount of water use. The Transpiration Ratio is calculated by dividing vine transpiration by Penman-Monteith crop evapotranspiration. Irrigation timing can then be determined by the Transpiration Ratio.

More Information

Visit the Implexx Sense website for detailed information on the Implexx Sap Flow Sensor and more case studies on irrigation and sap flow:

www.implexx.io

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