2016

A Lightweight Moisture Stress Indicator for VSP trained Vitis vinifera Grown in Sandy Soil

DRAFT July 31, 2016

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ABSTRACT

To develop a lightweight, moisture stress indicator for irrigated, VSP trellis trained Vitis vinifera, we used traditional plant moisture parameter gathering technologies to develop a soil, plant and climate dataset for a small, California Central Coast vineyard. We found that, when the plants have transitioned from the phase of vegetative growth to focus on developing berry maturity, and when soil moisture is limited, infrared thermometry may be used to quickly characterize moisture stress and therefore inform further irrigation scheduling decisions.

1. Introduction

Conditions for plant establishment, growth, and yield in the Central Coast of California are highly variable, these areas are subjected to difficult environmental stresses imposed by wind, semi-annual rainfall, and the influence of marine fog.

Generally, the Central Coast has a Mediterranean climate characterized by hot, dry summers with cool nights, exactly the inverse of the climates of Bordeaux and Burgundy which are cooler, with wet summers and warm nights. The dominant Central Coast varietals, Chardonnay, Cabernet and Pinot Noir, are being grown outside of their native French comfort zones, requiring precise viticultural attention to produce quality fruit.

Fruit maturity after veraison is traditionally measured objectively in the context of sugar concentration, and then subjectively by taste prior to the harvest decision. However, it is the more complex chemical composition of flavenols and anthocyanins that promote the varietal character of these grapes[1], but monitoring the progression of chemical composition is time-consuming and expensive. As a result, growers rely on simple, cheap, fast tools to sample sugar and acid, and assume that chemical composition is developing in the berry at the same rate.

Moisture stress improves the desirable chemical composition of the berry[2]. In intact plants, water stress can enhance secondary metabolism, particularly biosynthesis of flavonoids such as anthocyanin.[3]

This project proposes a simple plant moisture availability indicator that supports the coarse grained tool of irrigation scheduling used as the primary means of regulating moisture stress in Central Coast vineyards. This indicator should help the grower shift the gears of the vineyard away from from a phase of vegetative growth to a focus on accelerated cluster maturity.

[1] Conde, *et al.* (2007)
[2] Prichard ()
[3] He, *et al.* (2010)

1.1. Study Site

The investigation was carried out at the 1.6 hectare (4 acre) Alan Hancock College vineyard in Santa Maria, California. The Santa Maria Valley itself lies between the Sierra Madre Mountains and the coastline of the Pacific Ocean. The valley is approximately 50 kilometers (30 miles) long and 16 kilometers (10 miles) wide at the widest part, having an irrigated agricultural area of approximately 20,000 hectares (50,000 acres). Santa Maria is located at the north–west quadrant the county which includes both urban and agricultural development. Primary crops include a variety of vegetable crops (Lettuce, Celery, Broccoli, Cauliflower, Spinach), Strawberries and Vineyards.

The setting has a mean annual precipitation of 300 mm to 500 mm (12 to 20 inches), a mean annual air temperature of 16 degrees Celsius (61 degrees F), and a frost-free period of 190 to 300 days.

The AHC vineyard is essentially flat and consists of deep, sandy soil. As described by the USDA National Cooperative Soil Survey, the soil is classified as “prime farmland if irrigated” in the Santa Maria floodplane. The typical profile of this Sorrento Sandy Loam is:

H1 - 0 to 26 inches: sandy loam
H2 - 26 to 40 inches: stratified sandy loam to loam
H3 - 40 to 60 inches: stratified gravel to sand

The vineyard is divided into two blocks, the south block contains clones of pinot noir, the north block contains rows of torrontes, chardonnay, cabernet, pinot noir, syrah, alberino, plus several random varieties in 4 “library” rows. The vineyard is irrigated with Santa Maria city water distributed on demand via drip system emitters. Plants are supported by a VSP trellis, rows are oriented in a north-south direction.

Study Cultivars, Moisture Probe Locations, and Canopy Temperature Collection

This study was conducted in parallel with the 2016 AHC Regulated Deficit Irrigation and Shoot Thinning study in 10 rows of Chardonnay. Two probe assemblies provide the RDI measurements at each end of one of four of the RDI rows. The Chardonnay canopy is very dense, allowing for confidence in collecting IRT measurements.

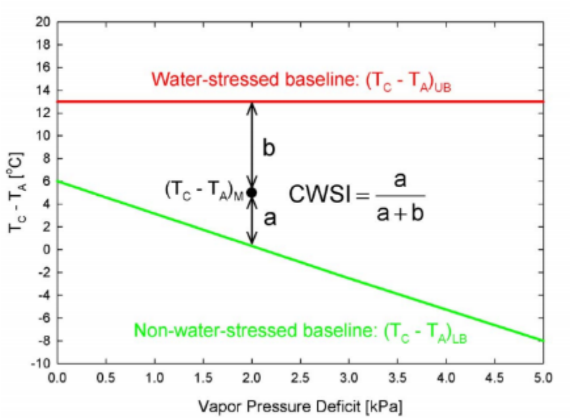
“Regular Irrigation” soil moisture measurements were taken from probe stacks in the south block of Pinot, the Cabernet and from the Chardonnay. These last two probe locations are very close to each other and are used to generate the Chardonnay “regular irrigation” averages.

Soil moisture data is also collected from the north east corner Syrah, but this section has proven to be significantly drier that the other four regular irrigation sites, its data is omitted from the vineyard averages.

General Detection of Water Stress in Plants

Canopy Temperature

The Crop Water Stress Index CWSI[4] (Idso et al, 1981; Jackson et al, 1981) describes water stress in the context of canopy and ambient temperature for a field crop. Based on the recognition that active plant respiration cools the leaves of well watered plants, the investigators described a canopy-to-ambient delta baseline for both well-watered plants and "non-respiring" plants. Combined with an adjustment for the vapor pressure deficit, the formula uses the current canopy temperature to calculate the CWSI index between 0 (no stress) and 1 (max stress). [5]



CWSI applications in many trials involve the use of an IRT with a fixed view angle and height above the canopy. [6] [7] These configurations often involve a crop canopy that covers the soil and includes, in the field of view, foliage that receives direct sunlight. The intention is to develop a measurement of field-scale canopy temperature [8]

Other Temperature Indicies

Degrees Above Non-Stressed (DANS) and Degrees Above Canopy Threshold (DACT) have been developed for corn and were well correlated with leaf water potential.[9] DACT, in particular, is an example of an index that is easily calculated and is correlated with soil water deficit.

1.5 Leaf Stomatal Conductance

Leaf stomates

Plant water relations are often governed by stomatal regulation of gas exchange. Stomata act as regulators of transpiration rates, by responding to changes in soil moisture or evaporative demand they regulate plant water status (Ψ). Species and varieties with isohydric behaviour are able to maintain tight control of Ψ over a range of environmental conditions, while Ψ in anisohydric plants oscillates in response to environmental changes. [10]

Vitis vinifera varieties are known to be diverse in their drought tolerance, traversing the isohydric-anisohydric spectrum. Isohydry is generally attributed to the strong stomatal control of transpiration rate. Anisohydric plants typically exhibit less stomatal control over evaporative demand and soil moisture, allowing large fluctuations in leaf water potential. [11] [12]

Stomatal closure in response to increasing VPD might be an effective strategy to avoid excessive water loss under drought conditions and prevent leaf water potential from falling to dangerous levels. [13]

Plant Water Potential

Plant water potential is often measured using a pressure chamber. [14] Extensive reviews on the pressure chamber measurements are available elsewhere. [15]

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[4] Jackson *et al.* 1986
[5] USDA, Crop Water Stress Detection
[6] DeJong *et al.* 2015
[7] Blonquist *et al.* ()
[8] Gonzalez-Dugo et al. 2005
[9] DeJong *et al.* 2015
[10] Rogiers 2009
[11] Hugalde *et al.* 2009
[12] Schultz 2009
[13] Patakas, 2005
[14] Boyer, ()
[15] Boyer, ()

Methods and Materials

Soil Water Content Measurements

Volumetric soil moisture was measured with probes (Decagon Devices models 5TM and EC-5, Pullman, WA) using capacitance/frequency domain technology. Probes were installed in pairs, one at a depth of 40 cm, the other at 80 cm, in 7 different locations in the vineyard.

Data was manually collected with a handheld read-out device (Decagon Devices, model ProCheck, Pullman, WA).

Plant Measurements

Petiole water potential was calculated, using a pressure chamber (Soil Moisture Equipment Corp. model 3005, Goleta, CA), by averaging measurements of 3 developmentally similar, fully expanded leaves. Measurements were taken within 2 hours post-solar noon.

Individual temperature measurements of 3 developmentally similar, fully expanded leaves from different plants, each taken from a distance of about 15 cm with an Infrared thermometer (Fluke Corporation, model 62 Max, Everett, WA), were averaged to record a shaded canopy temperature. Measurements were taken within 2 hours post-solar noon. Leaf emissivity is assumed to be .95. The stated accuracy of the IRT is +/- 1.5 degrees Celsius in the vineyard operating environment.

Stomatal conductance was calculated using a steady state porometer (Decagon Devices model SC-1, Pullman, WA) that measures the actual vapor flux from the leaf through the stomates and out to the environment. The device was re-calibrated immediately prior to each data collection session. Measurements were taken within 2 hours post-solar noon. The stated accuracy of the porometer is +/- 10%.

Porometer data gathering was discontinued after encountering problems with data quality.

Environmental Measurements

The temperature of the local canopy micro-climate was measured with a sling psychrometer (NovaLynx Corp model 225-571-A, Grass Valley, CA) hanging on the shaded side of the canopy, recording the dry bulb temperature to correspond with a set of leaf temperatures and petiole water potential measurements collected at the same time. The psychrometer was operated in the shade to record the wet bulb temperature for each data set. The stated accuracy of these thermometers is +/- 0.55 degrees Celsius.

Atmospheric Data

General atmospheric data was collected online from the Weather Underground station KCASANTA71[16] approximately 1.2 km from the vineyard.

Insolation data was collected online from the NASA Prediction of Worldwide Energy Resource. [17]

ETo data was collected online from the California Department of Water Resources California Irrigation Management Information System site *Santa Maria II* (#232) which is maintained by the cooperator, the City of Santa Maria Utilities Department. [18]

[16] Weather Underground KCASANTA71
[17] NASA Prediction of Worldwide Energy Resource
[18] California Irrigation Management Information System

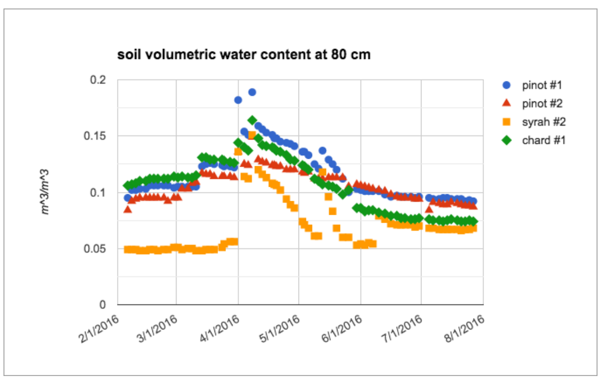
Data Analyses

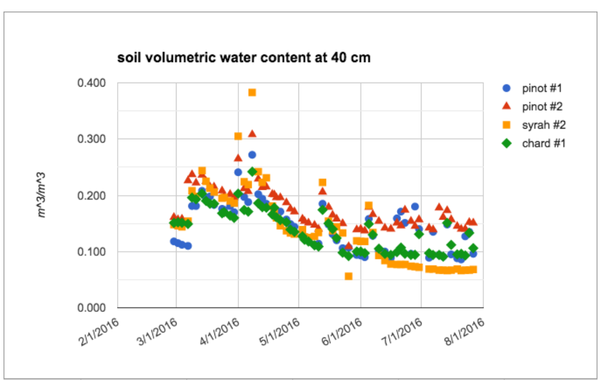
Volumetric Soil Moisture

Six sensor stacks were installed in the vineyard in early February, 2016. This included two stacks in the south block Pinot Noir, one in the north east corner of the Syrah, one in the Chardonnay, and one in the Cabernet.

Locating the sensors at exactly 40 cm and 80 cm was difficult given the variance in the soil mound height in the different vineyard rows. The initial data was not uniform from stack to stack, suggesting a lack of soil composition uniformity across the vineyard.

Importantly, the Syrah stack reported numbers significantly different from the other stacks. A second Syrah stack was added 2.5 meters (8 feet) from the first in the adjacent row to try and determine if there was a sensor or installation problem. This second stack confirmed that this corner of the vineyard was significantly drier than the other stack locations.





Eventually, in July, to integrate the RDI and shoot thinning experiment that was also being conducted in the vineyard, two additional probes stacks were installed. One (Chardonnay #2) was installed in the Chardonnay RDI row, and the other (Chardonnay #3) was installed in the Chardonnay regular irrigation row approximately 10 meters from the existing Cabernet stack.

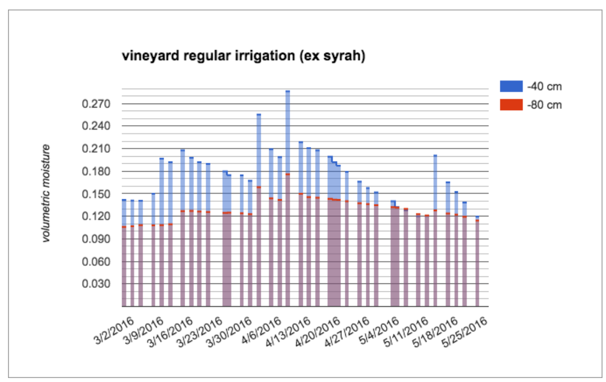
“Syrah #1” was de-commissioned and re-installed as “Chardonnay #2”.

For the purposes of data averaging, the south block Pinot Noir stacks are considered as experiencing the “regular irrigation” regime. The Cabernet stack, being 2.5 meters (8 feet) from a Chardonnay regular irrigation row, is averaged with Chardonnay #3 to develop “Chardonnay regular irrigation” data points.

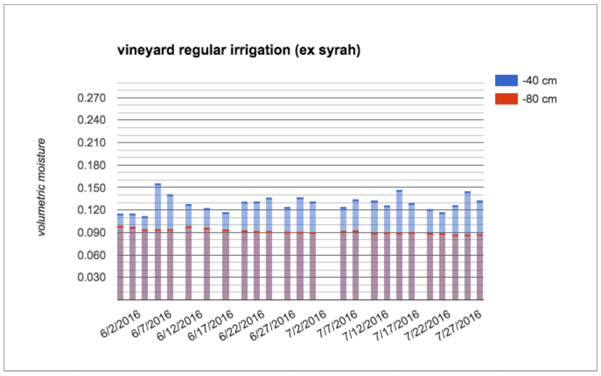
The Syrah stack(s) are considered as introducing a skew to the data and are not included in either the RDI or regular irrigation averages.

Soil Moisture Response

In the early Spring, when the 40 cm moisture levels are at about 20%, rain and irrigation events are registered at the 80 cm level.



In early and mid-Summer, 80 cm moisture levels off at about 9%, and normal irrigation events are no longer registered at this depth. It appears that plant demand, upper soil storage, and environmental evaporation are consuming the entire irrigation volume as it becomes available.

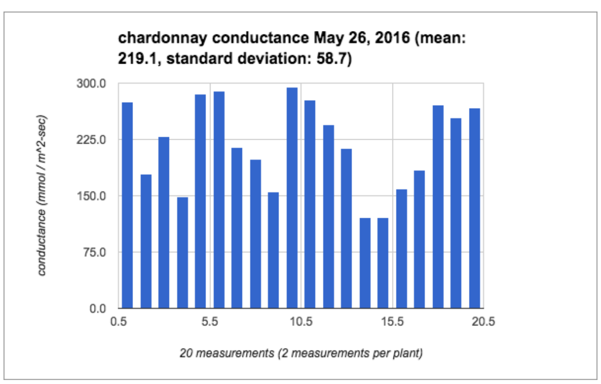


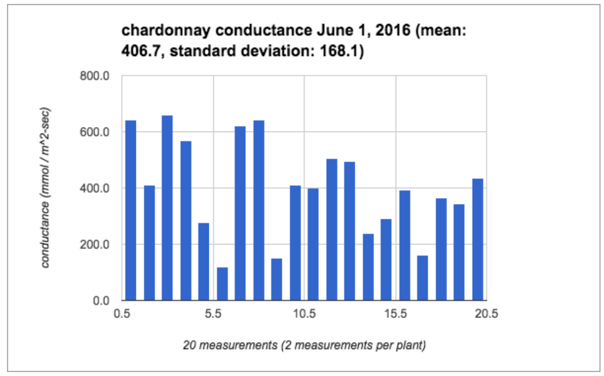
Stomatal Conductance

The porometer, with a specified accuracy of +/- 10 percent, did not yield data that correlated with other moisture status indicators. Perhaps instrument calibration, which depends on ambient relative humidity, contributed to a suspiciously large standard deviations as sling psychrometer surveys showed humidity variation across the vineyard. Large variations in conductance in similar leaves on the same plant further limited the apparent utility of the data.

The general instrument sensitivity and cycle time for obtaining individual measurements did not support the study objective of identifying a “lightweight” moisture stress indicator. Consequently, the use of this instrument was discontinued.

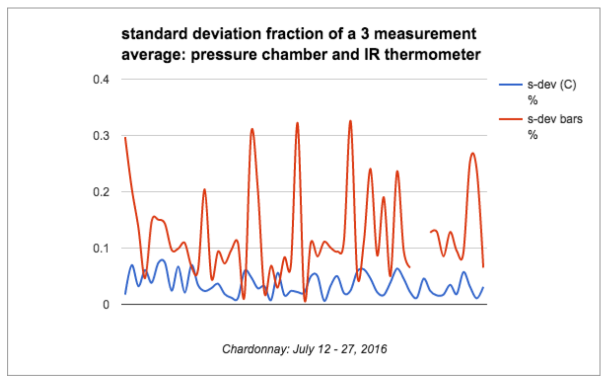
Example data for two stomatal conductance surveys:





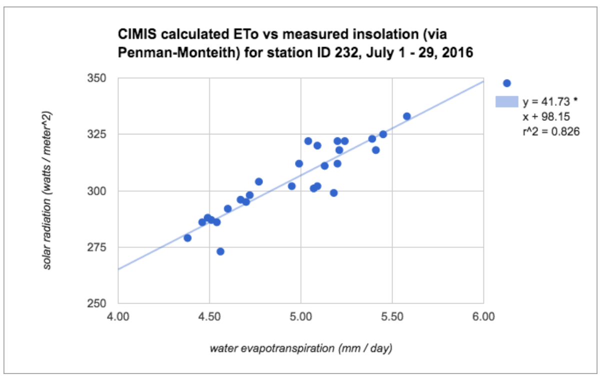
Stem Water Potential

Pressure chamber measurements were found to be sensitive to leaf development status and sun orientation. After focusing exclusively on canopy shaded side leaves, it became apparent that the minimum sample size should be at least 3. Even then, the standard deviation of these samples often reached 20%, several times it reached 30%.



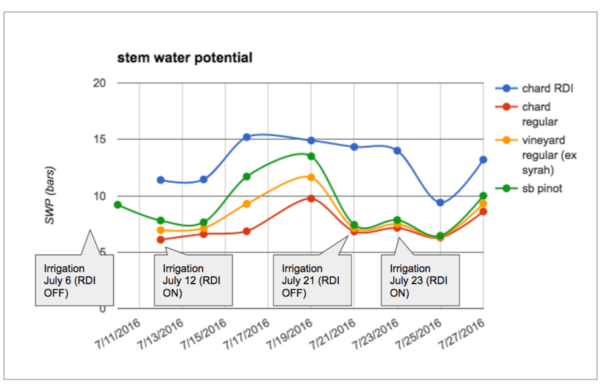
We propose that CIMIS evapotranspiration (ETo) may be used as a proxy for a reference idealized ET demand in the vineyard. We believe that vineyard (soil plus plant) respiration should increase proportionally with solar insolation and will therefore be proportional to CIMIS ETo.

However, there are vineyard features that do not align with the CIMIS model. CIMIS stations survey a well watered field crop (grass) with a managed canopy. In contrast, the vineyard includes areas of exposed soil, dead cover crop (in July), some weeds, and a canopy that has stopped developing. The plant's moisture storage capacity (berry volume) is expanding in the July timeframe.



Pressure Potential and Soil Moisture

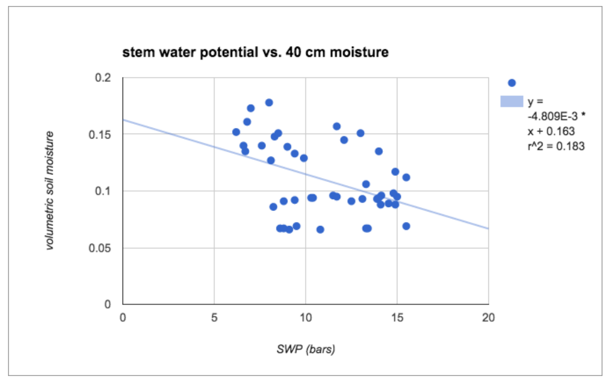
Petiole pressure potential, or "stem water potential" (SWP), was found to track both absolute and relative (in the context of regular vs. RDI irrigation) soil moisture availability.

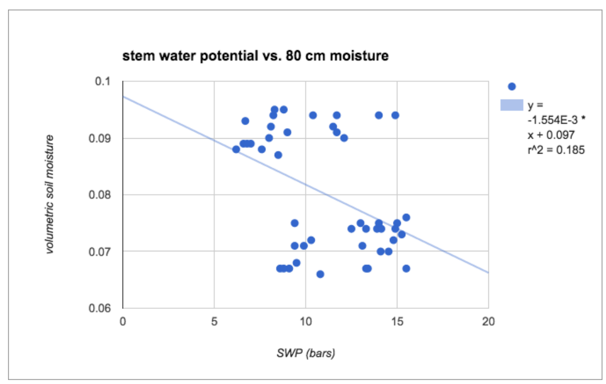


We find that stem water potential is not well correlated to soil moisture at either 40 cm or 80 cm.

The 40 cm moisture status suggests that, for this particular developmental stage, plant water status, and generalized soil moisture level, the variability of stem water potential is governed by the plant, and not by soil moisture.

This 80 cm moisture status suggests that if the plants are pulling any water from the soil below 80 cm, that soil moisture is being actively replenished by matric pressure from below, or matric plus gravitational pressure from above.





Discussion

The energy budget describing the rate of energy transferred to or from a leaf per unit area is simplified to be

$$R_n + H + E_l = 0$$

Where

R_n is the net radiation flux

H is the sensible heat flux (the effects of diffusion, convection and conduction)

E_l is the latent heat lost by evaporation

The energy flux due to photosynthesis is known to be small compared to these terms and is ignored. [19]

The effect of transpiration of leaves on the shaded side of a VSP trellis is simplified for leaves that are not subject to airflow (wind) and are not in contact with warmer leaves from the sunlit side of the canopy. In this case, for steady state where the leaf temperature is not changing, the rate of energy gained from (reflected) solar radiation must be equal to the rate of energy lost by diffusion and evaporation.

The diffusion of water vapor is governed by a difference in the vapor pressure of the evaporating surface, a function of water potential (SWP) and temperature, and the vapor pressure of the bulk air, a function of water content and temperature.

The wet bulb of a sling psychrometer may be used to measure the lowest temperature to which diffusion and evaporation will drive the leaf surface for a given ambient temperature and relative humidity. This wet bulb temperature associates the water potential of a "well watered" plant and the capacity of the bulk air to receive moisture from the leaf.

Since maximum leaf transpiration for a given humidity will drive a shaded leaf to the wet bulb temperature, when measuring the actual leaf temperature during periods of maximum net radiation (ie, solar noon), the difference between the actual leaf temperature and ambient can then be used to construct a "wet bulb index" as follows:

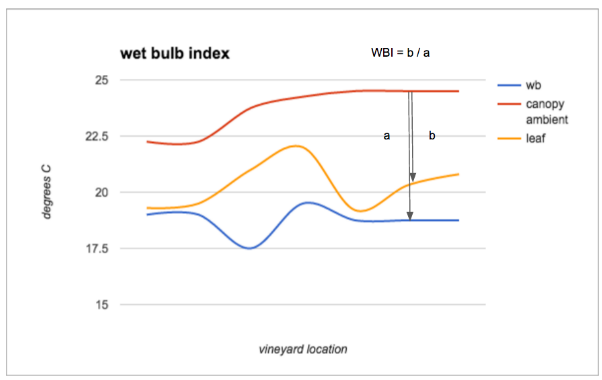
$$WBI = (T_l - T_a) / (T_{wb} - T_a)$$

Where

T_l is the leaf temperature

T_a is canopy ambient temperature

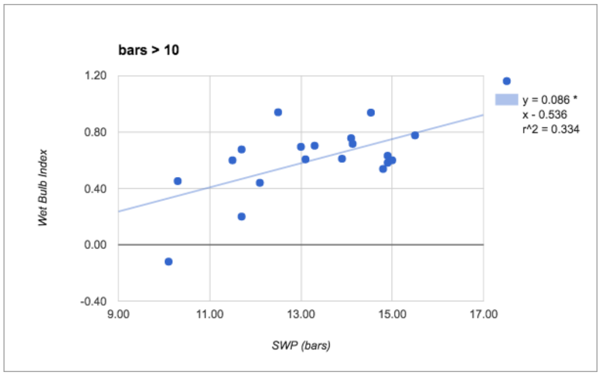
T_{wb} is the wet bulb temperature

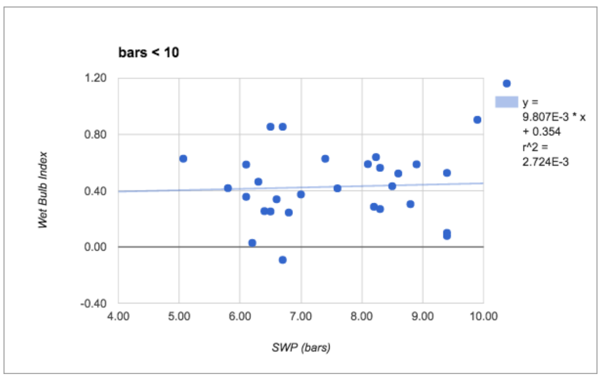


This index may be calculated relatively quickly if the sling psychrometer is first hung in the canopy, then three leaves are sampled to yield an average leaf surface temperature, and finally the ambient and wet bulb temperatures are recorded from a stabilized psychrometer.

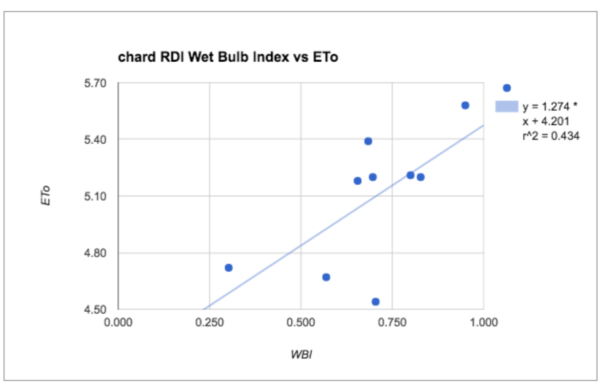
[19] Kramer, 1995, pp. 204 - 210

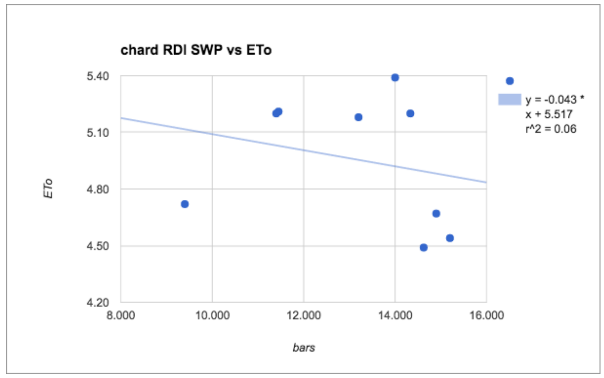
For July, during a phase of restricted vegetative growth, this index seems to be more informative when the SWP of the plants is greater than 10 bars.

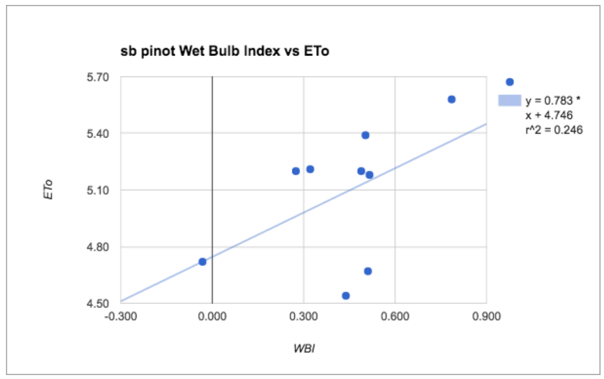


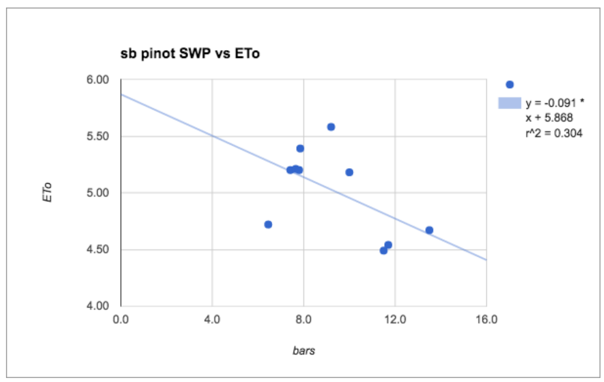


In the context of regionally idealized ETo, the WBI seems to be more strongly associated than does SWP, especially in a reduced irrigation regime.









Conclusions

Wet Bulb Index, a lightweight indicator that relates leaf temperature to plant moisture availability and environmental conditions, seems promising as a means to inform VSP vineyard irrigation decisions. It relies on simple instruments and can be used by operators with minimal training.

The index may be calculated quickly, and is more sensitive when plants are under moisture stress. There is opportunity to further evaluate the effects of error propagation in these measurements and to obtain data earlier in the plant growth cycle.

Acknowledgements

Ric Fuller, and Alfredo Koch of the Alan Hancock College Department of Agri-Business.

Mark Battany of the University of California Agriculture and Natural Resources, UC Cooperative Extension for methodology support.

Michael Sandoval of Sandoval Ranch and Vineyard for logistical support.

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