

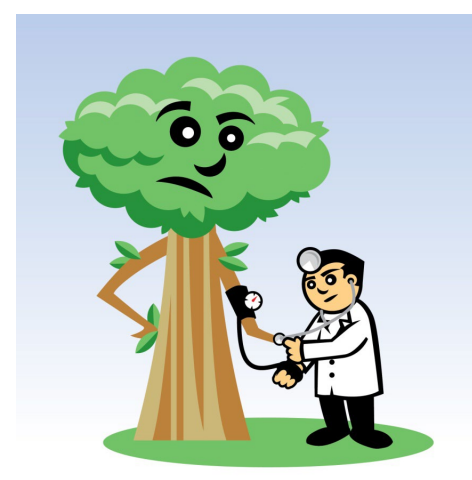
## Abstract

From a practical standpoint, on-farm irrigation management can be simply considered as "how much and when" (i.e., irrigation amount and frequency), but since the objective of irrigation is to influence the plant, a plant-based indicator is needed to determine if the amount is 'enough' and if the frequency is not 'too soon or too late.' Based on the successful use of manual (pressure bomb) measured midday SWP as a plant-based indicator, a number of automated devices to directly or indirectly measure SWP have been recently developed/commercialized for use in irrigation management. One important goal of this research is to evaluate the most promising of these methods and to contribute to the development of a method or methods that are as reliable as the pressure bomb. Two commercial methods for directly measuring SWP (FloraPulse and Saturas), and one commercial method for indirectly measuring plant water status (Phytech) were compared to manual pressure bomb measurements in terms of their sensitivity to irrigation management as well as the consistency of their relation to pressure bomb SWP. All sensors showed a similar overall seasonal pattern with generally low levels of stress in the spring and high levels of stress as a result of deficit irrigation at hull split and harvest. As found in 2021, the FloraPulse sensor showed a very high level of agreement to pressure bomb SWP throughout the season, with an average deviation of 1.5 to 1.8 bars. The Saturas sensor agreed with pressure bomb SWP during some but not all of the season, and also had a much higher variability (4.6 bar), even after adjusting for a 1 day delay in the responsiveness of this sensor. The Phytech sensor showed the lowest agreement with pressure bomb SWP and a wide range of variability (3.8 to 8.8 bar, depending on the year). As reported previously, this sensor appears to be very sensitive during the early stages of stress, but less sensitive as stress increases. We are still in the early days of commercialization for plant-based water stress sensors. Thus far the FloraPulse sensor appears to be the most reliable, but in addition to sensor readings, irrigation management decisions should be based on periodic pressure bomb readings both on the same tree(s) as the sensor tree(s) to verify that the sensors continue to be accurate, as well as additional trees in the irrigation block, to verify that the sensor trees is/are typical of the block.

## Introduction

The fundamental objective of irrigation management in almond (or any crop) is to manipulate plant water availability as a means to influence plant activity, so that orchard health and production is optimized under the current environmental conditions. Water availability affects almost every aspect of plant growth and productivity, so timely and accurate plant-based irrigation management represents a powerful tool under the control of the grower. In the case of almonds for instance, it is well established that imposing mild to moderate water stress during hull split improves harvestability and can reduce hull rot. The pressure bomb can be used to measure tree water stress (SWP) at any time of day, but has been mainly used to provide a snapshot at the time of the maximum daily stress (midday). Research has demonstrated that midday SWP in almond is well related to many fundamental plant physiological responses, such as stomatal opening, photosynthesis, tree growth, and kernel weight. Based on the consistency and reliability of pressure bomb measured SWP, a number of automated methods have been recently commercialized to either directly or indirectly measure SWP. The two direct methods suitable for field use are the micro-tensiometer developed by FloraPulse, and the osmotic cell developed by Saturas. An indirect method based on micrometer (dendrometer) measurements of the daily shrink/swell patterns in the trunk has also been developed and commercialized by Phytech. These methods have the potential to open new opportunities for more precise irrigation management, particularly in terms of when and how much water stress can be imposed on almonds to optimize economic tree productivity.

## Objectives



- 1) Compare different automated SWP methods to pressure bomb SWP at the almond lysimeter site (Kearny Ag. center) in the following areas:
  - 1) Consistency of response to irrigation events in the short term.
  - 2) Stability of the relationship to pressure bomb SWP over the season (long term).
  - 3) Degree of uncertainty in measured (or predicted) SWP (bars).
- 2) Determine an irrigation frequency and amount which will result in a stable day-to-day level of midday SWP.



## Methodology/Results

### Commercial sensors tested: all are trunk installed

- FloraPulse (gives SWP values every 20 minutes)



- Sensor is imbedded into the active water transport tissue (wood).
- Directly measures the water tension in the wood.
- Measurement recorded by a datalogger every 20 minutes and made available on the internet.
- Measurement is made in bars (or MPa) and should match SWP measured by the pressure bomb at the same time.

- Saturas (gives a daily calculated midday SWP)



- Sensor is imbedded into the active water transport tissue (wood).
- Determines the water tension in the wood by measuring the pressure in an enclosed fluid of known composition separated from the wood by a membrane (i.e., is an osmometer).
- 24 h average tension is calculated, and processed to give an equivalent midday SWP (bars or MPa), which is available on the internet.
- Measurement is made in bars (or MPa) and should match SWP measured by the pressure bomb at midday.

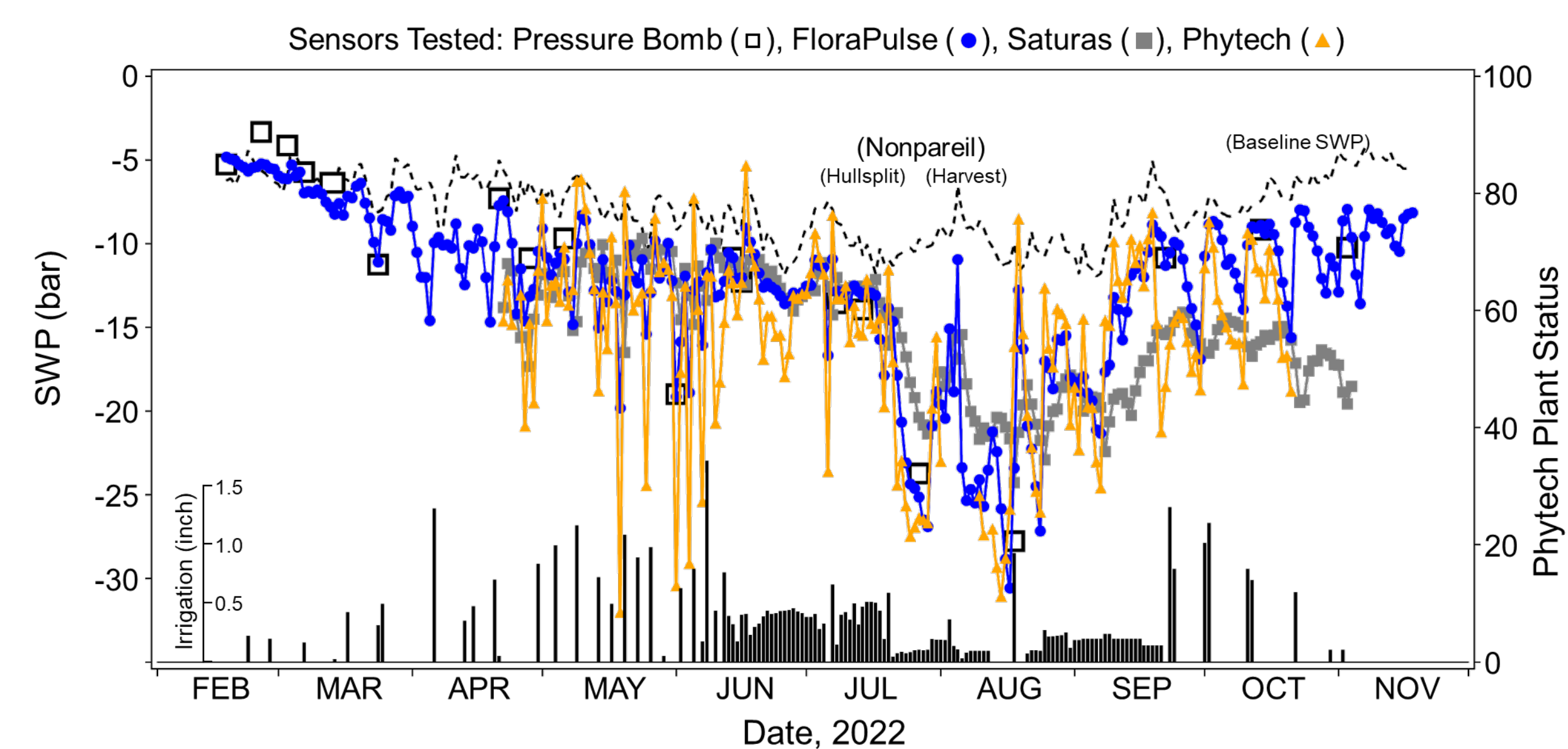
- ▲ Phytech (gives a daily value of plant status ranging from 0 to 100)



- Sensor is mounted on a screw anchored into the wood.
- Measures hourly micrometer changes in the size of the trunk.
- Daily patterns in size (daily growth and midday shrinkage), are analyzed to calculate a daily plant water status value that ranges from 0 (high water stress) to 100 (no water stress).
- Daily plant status is made available on the internet.

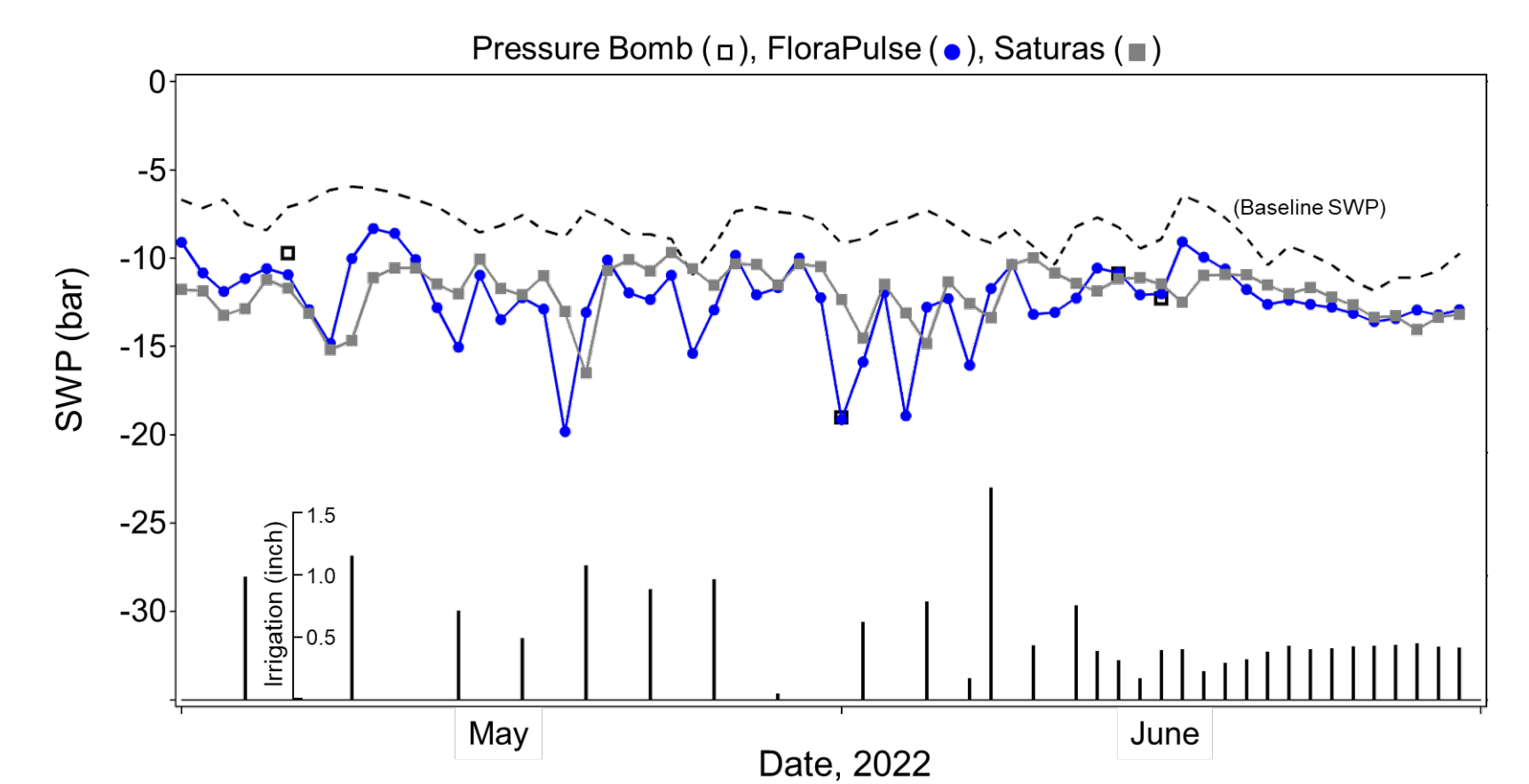
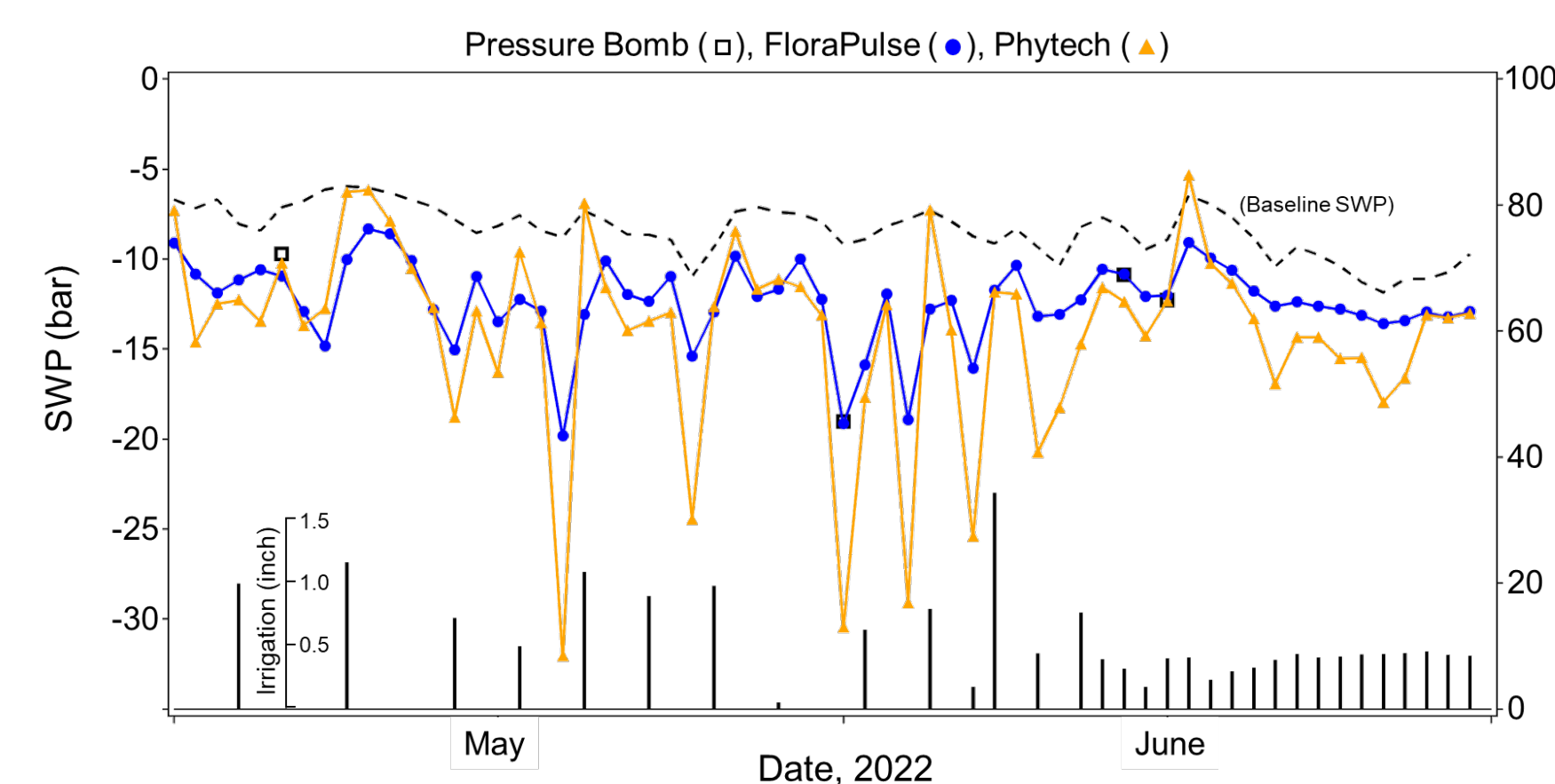
### Seasonal overview of irrigation management and sensor response

- Overall seasonal patterns of stress were similar in all sensors, although the FloraPulse sensor remained consistently close to pressure bomb SWP throughout the entire season, whereas Saturas showed less stress during harvest and more stress postharvest, and Phytech showed as much stress in May as was observed during harvest, which was not consistent with the pressure bomb or FloraPulse sensor.
- Note that the frequency of irrigation events (black bars at bottom of graph) increased from about weekly in April to daily in early June. This change was considered necessary to avoid the rapid increase in stress measured by all sensors at the end of each irrigation cycle (see analysis below).



### Detail of irrigation management and sensor response during the May/June irrigation transition

- All sensors showed rapid recovery in SWP (or plant status) immediately following irrigation, but drops in SWP near the end of each irrigation cycle.
- Compared to FloraPulse, Phytech consistently showed more severe drops in status near the end of each irrigation cycle, and Saturas less severe.
- These 'sawtooth' fluctuations in stress occurred even when irrigation frequency was every 2-3 days (Late May, early June), but disappeared with daily irrigation in mid-June.



### Overall statistical comparison between each sensor and pressure bomb measured SWP

- More SWP measurements were made in 2021 (100) than 2022 (11), but with similar results.
- FloraPulse had the highest correlation and smallest error of all sensors.
- Phytech, which is an indirect measurement of water stress, exhibited the lowest agreement with the pressure bomb and a wide range of variability (3.8 to 8.8 bar, depending on the year).
- Saturas values appear to show a delay of about 1 day.

Device	2022 (N=11)		2021 (N=100)	
	R-square	Error (bar)	R-square	Error (bar)
FloraPulse	0.93***	±1.8	0.93***	±1.5
Phytech	0.35 ns	±8.8	0.55***	±3.8
Saturas	0.51*	±6.3		
Saturas (+1 day)	0.67**	±4.6		

## Conclusions

Automated SWP sensors are now making it clear that irrigation frequency can be a key determinant of water stress, especially for the soil and weather conditions at this site (Fresno area, deep Hanford sandy loam soil). Based on previous results at the same site, when almonds drop to 20 bars at the end of the irrigation cycle (as occurred in late May/early June in 2022) whole tree water use is reduced on the order of 25% by stomatal closure. How important these short term periods of stress are for overall tree health and productivity in the long term is not known, but these sensors now open the door for research to answer these questions.

For the specific sensors evaluated as part of this research:

- 1) FloraPulse, which is designed to directly measure SWP, exhibited the closest agreement with the pressure bomb, and the lowest average variability (1.5 to 1.8 bar).
- 2) Saturas, which is also designed to directly measure SWP, exhibited agreement with the pressure bomb during some but not all of the season, and also had a much higher variability (4.6 bar), even after adjusting for a 1 day delay.
- 3) Phytech, which is an indirect measurement of water stress, exhibited the lowest agreement with the pressure bomb and a wide range of variability (3.8 to 8.8 bar, depending on the year), and, as reported previously, appears to be very sensitive during the early stages of stress, but less sensitive as stress increases.

