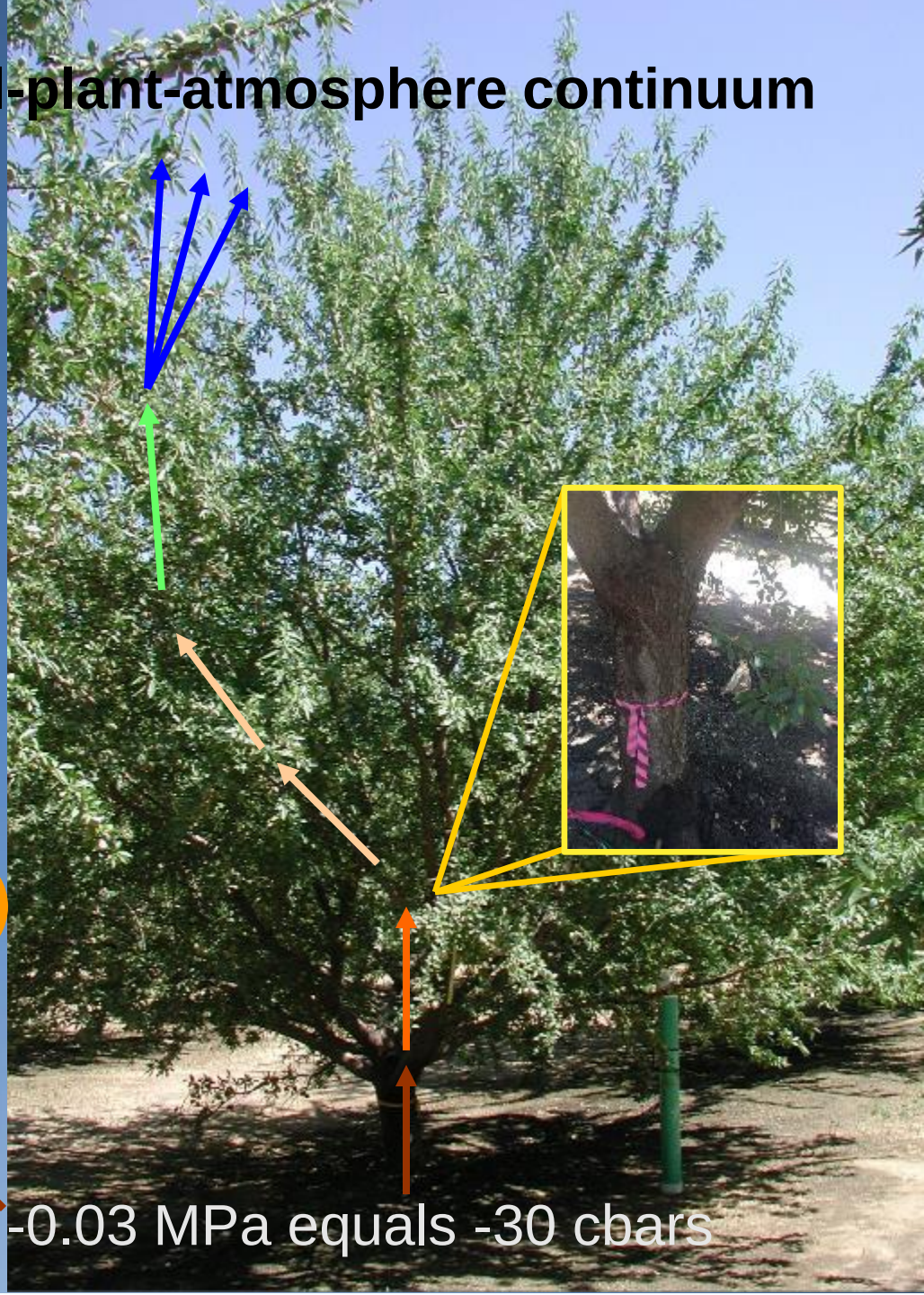
Methods to schedule irrigation in almond

- Calendar
- Plant water status
- Soil moisture measurements
- Evapotranspiration

Water potential in the soil-plant-atmosphere continuum

Location	(MPa)
Air above tree	-9.5
Air near leaf	-7.0
Air in leaf	-1.2
Xylem in leaf (6m)	-1.0
Xylem in scaffold	-0.8
Xylem in trunk-	-0.75
Xylem in root	-0.06
Soil	-0.03



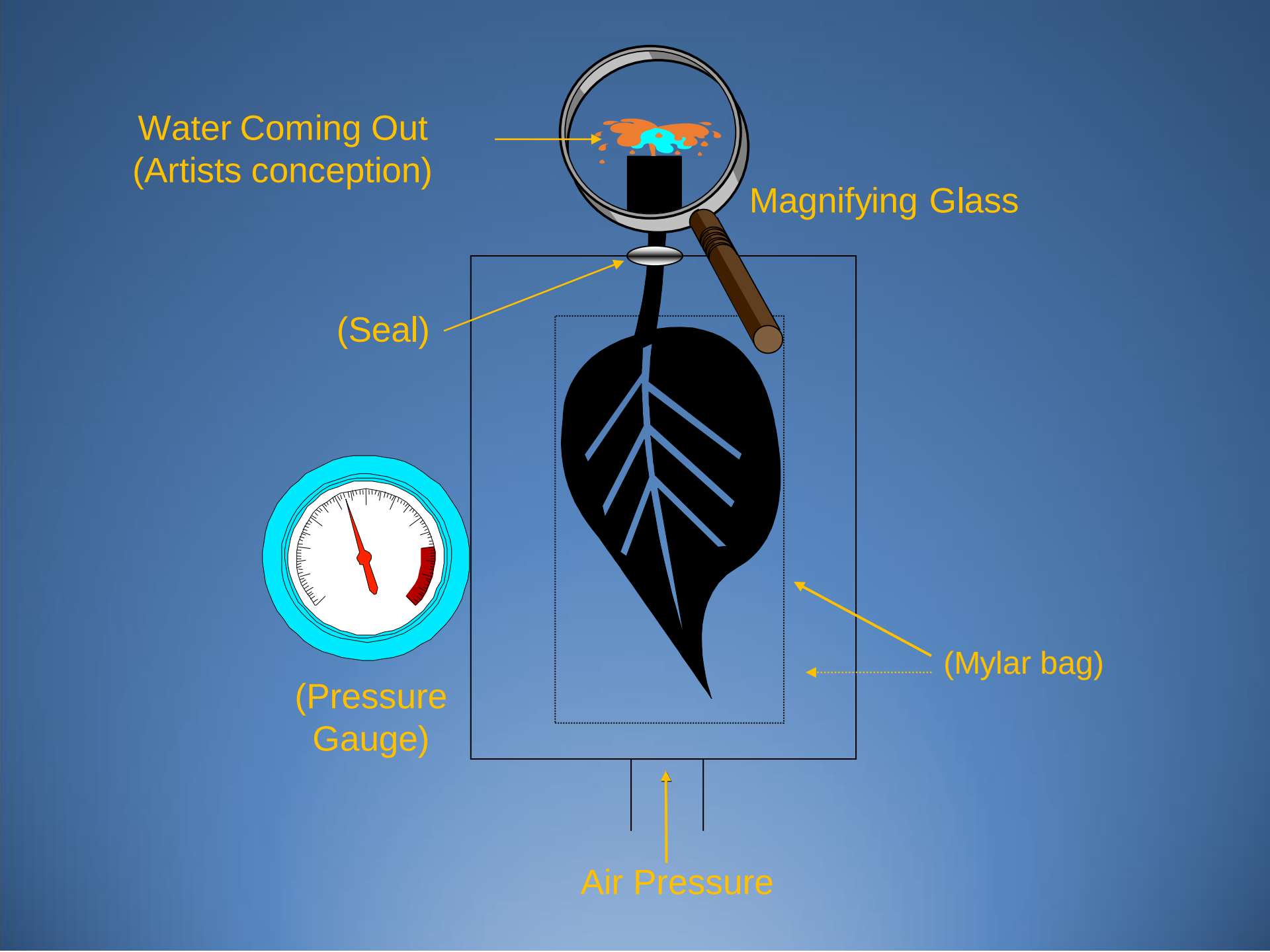
Midday stem water potential?

- A plant pressure chamber is used to measure the tension in a leaf

- Midday stem water potential is normally expressed as a negative value since you are measuring a tension in the xylem

- Water potential readings done on a bagged leaf at midday are known as midday stem water potential (MSWP)

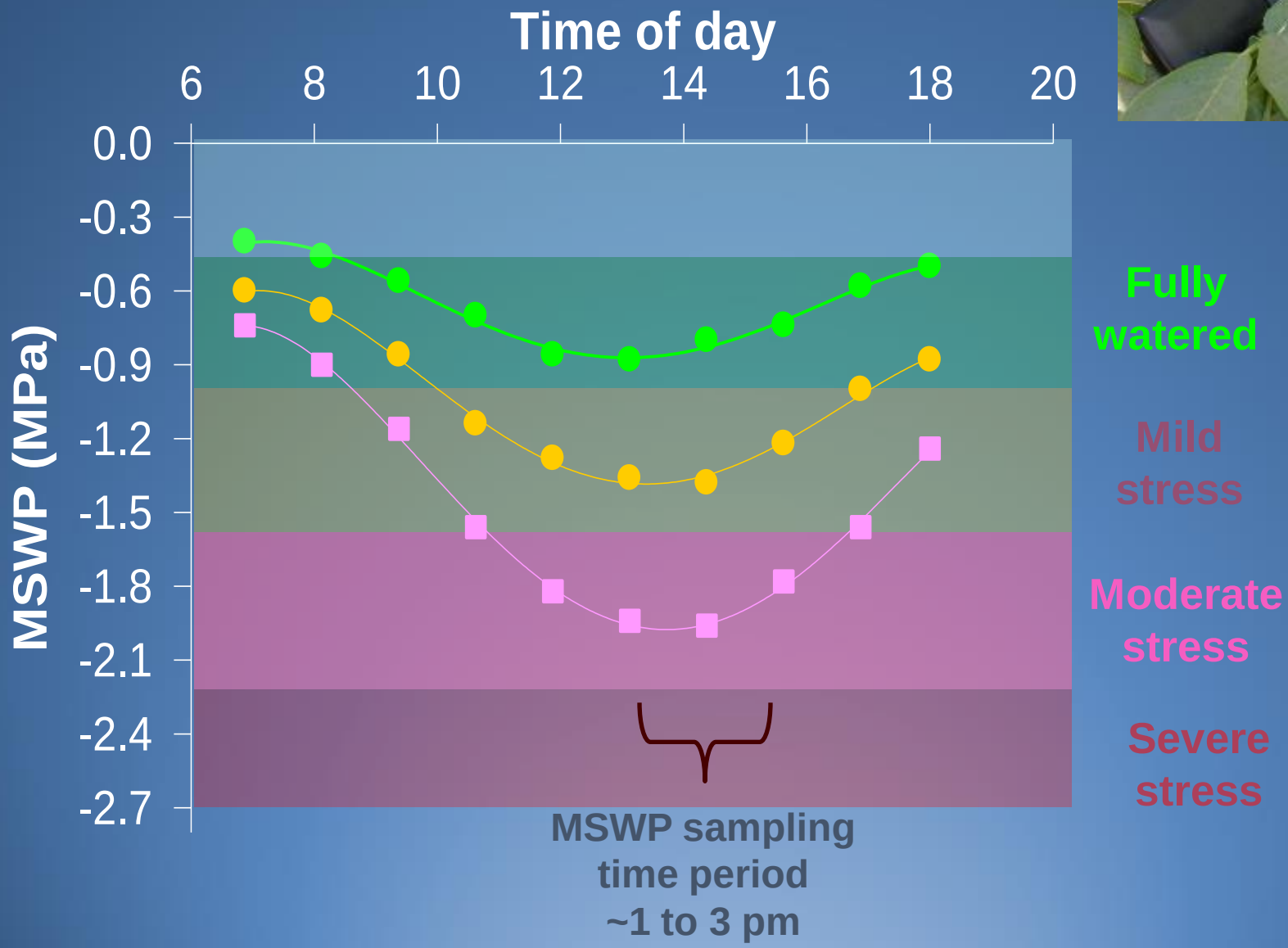
Bagging low, shaded leaf at least 15 minutes before sampling at midday- allows equilibration with water potential of the trunk

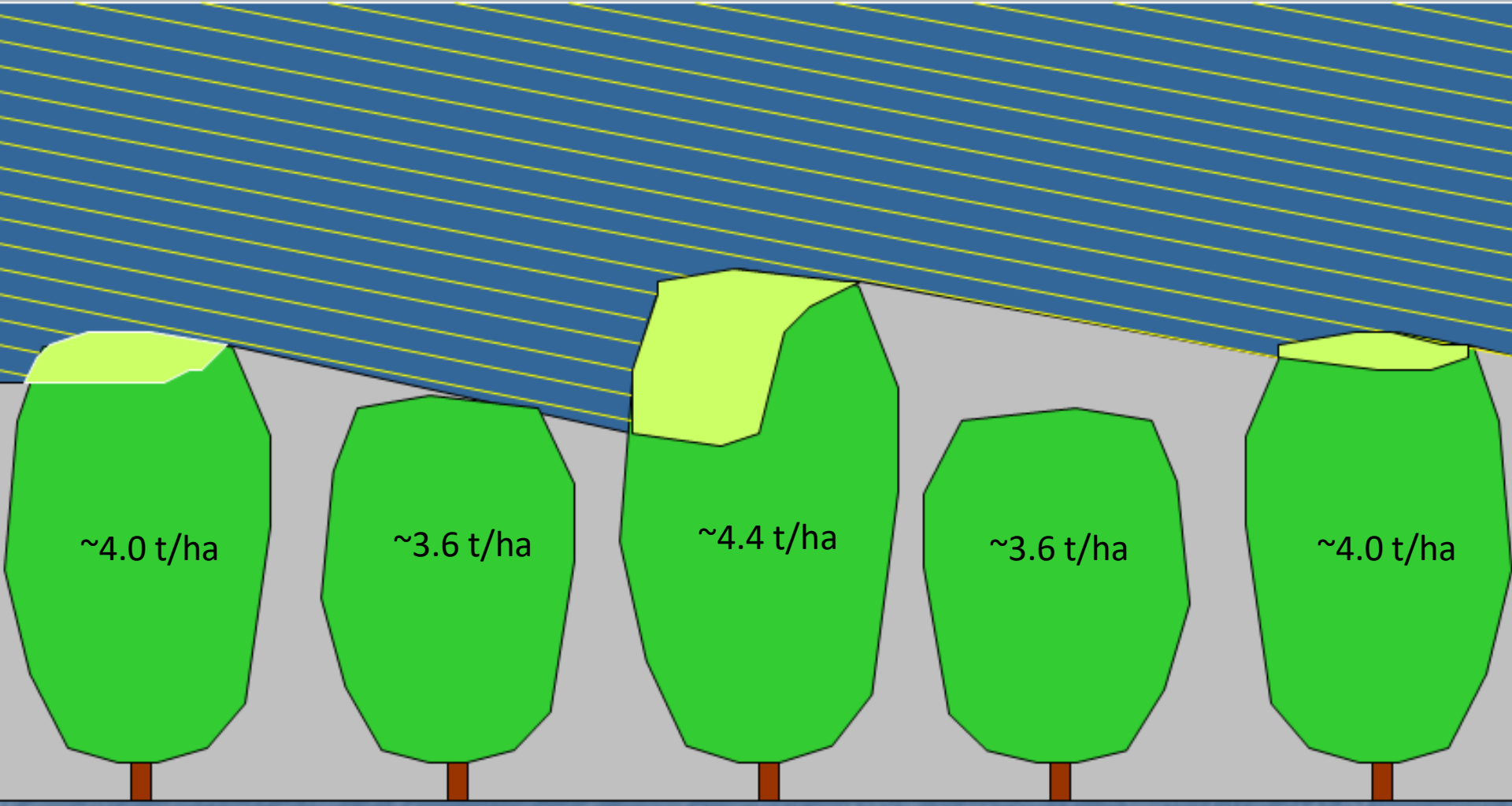

Water Coming Out
(Artists conception)
Magnifying Glass
(Seal)
(Pressure
Gauge)
(Mylar bag)
Air Pressure

Before end point

At end point- take reading just as water appears

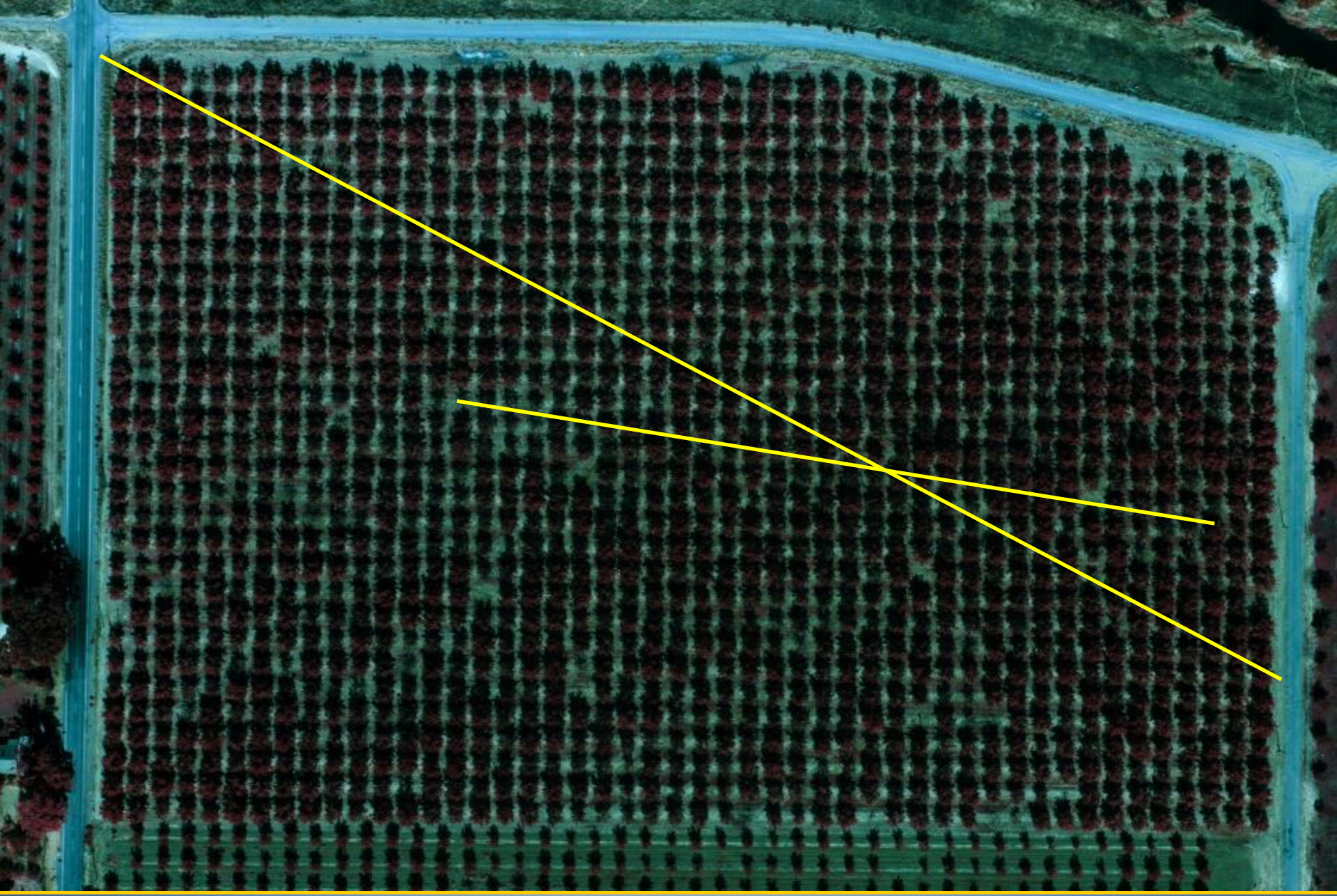
Almond Stem Water Potential





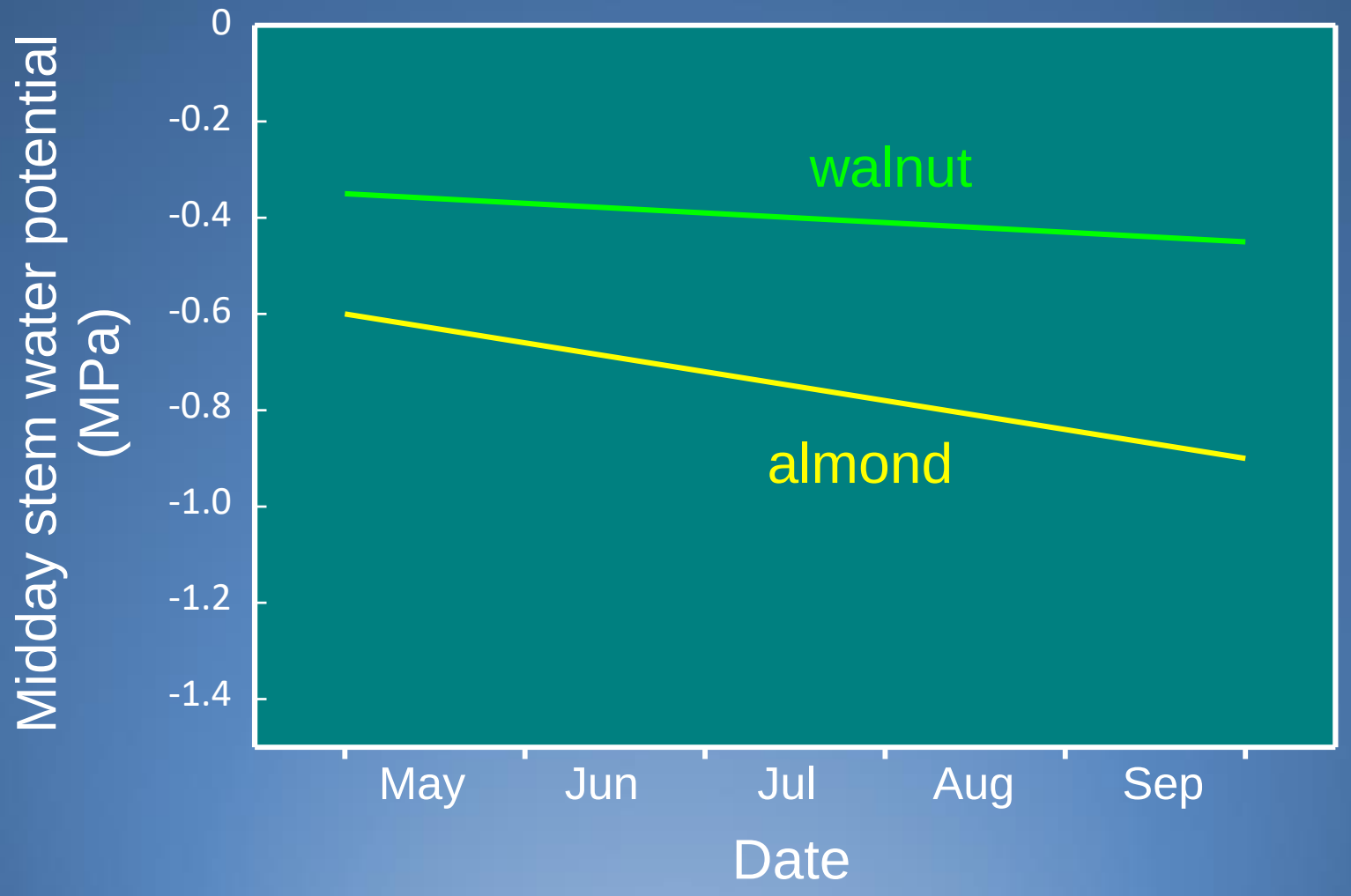
~20% of yield can be shifted from shorter to taller variety

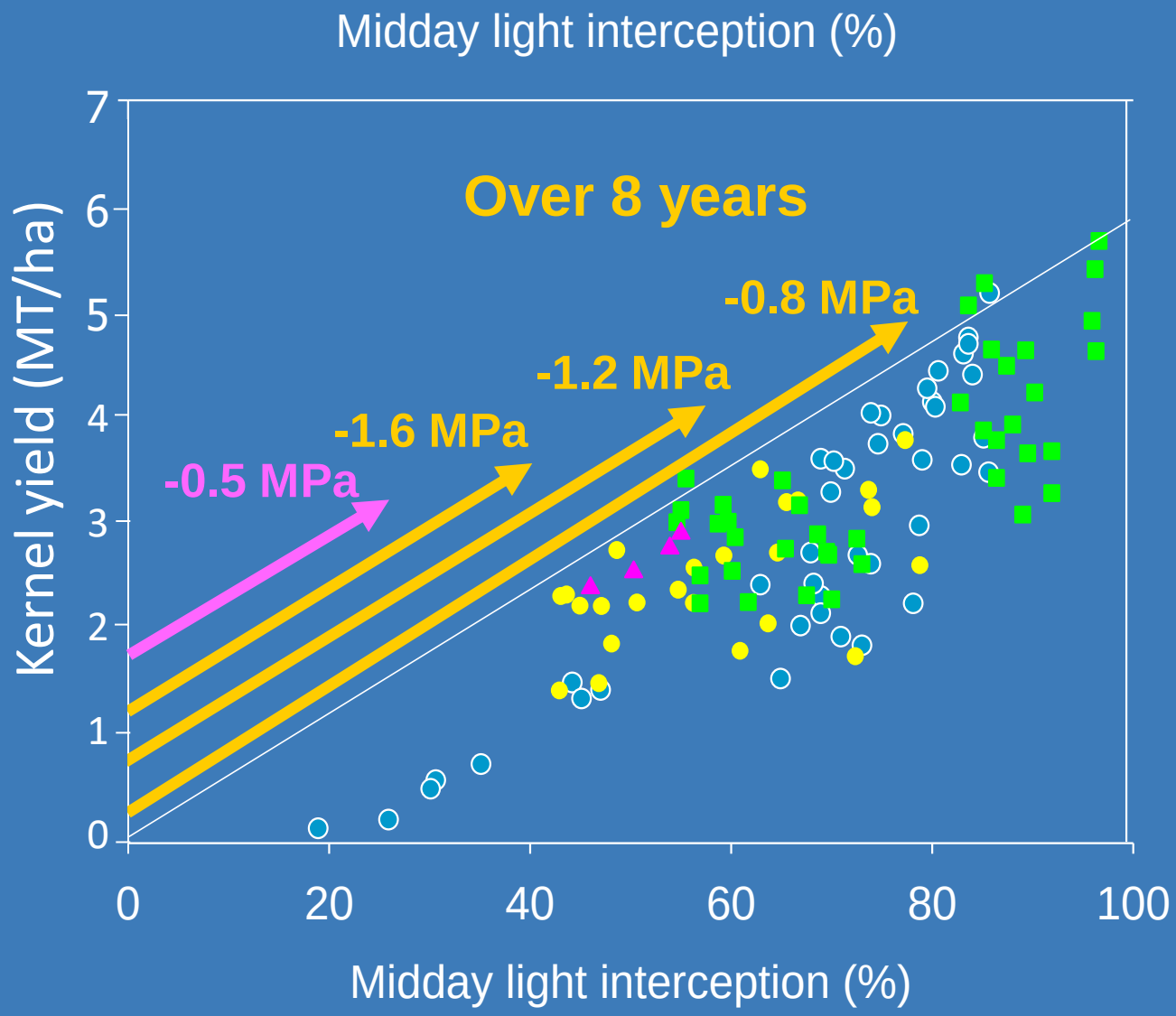
Water use can also be higher for taller variety



Where should your measure MSWP?

Almond-Walnut Comparison





Approximately 5% loss in rate of canopy development per 0.1 MPa of seasonal average midday stem water potential deficit

Midday Stem Water Potential (MPa) for a Fully Watered Almond

Relative Humidity (%)	Temperature (°C)												
	20	22	24	26	28	30	32	34	36	38	40	42	44
10	-0.66	-0.70	-0.73	-0.77	-0.82	-0.87	-0.92	-0.98	-1.05	-1.13	-1.21	-1.30	-1.39
15	-0.65	-0.68	-0.71	-0.75	-0.80	-0.84	-0.89	-0.95	-1.02	-1.09	-1.16	-1.25	-1.34
20	-0.63	-0.66	-0.70	-0.73	-0.77	-0.82	-0.87	-0.92	-0.98	-1.05	-1.12	-1.20	-1.28
25	-0.62	-0.65	-0.68	-0.71	-0.75	-0.79	-0.84	-0.89	-0.94	-1.01	-1.07	-1.15	-1.23
30	-0.61	-0.63	-0.66	-0.69	-0.73	-0.77	-0.81	-0.86	-0.91	-0.97	-1.03	-1.10	-1.17
35	-0.59	-0.62	-0.64	-0.67	-0.70	-0.74	-0.78	-0.82	-0.87	-0.93	-0.99	-1.05	-1.12
40	-0.58	-0.60	-0.62	-0.65	-0.68	-0.72	-0.75	-0.79	-0.84	-0.89	-0.94	-1.00	-1.07
45	-0.56	-0.58	-0.61	-0.63	-0.66	-0.69	-0.72	-0.76	-0.80	-0.85	-0.90	-0.95	-1.01
50	-0.55	-0.57	-0.59	-0.61	-0.64	-0.66	-0.70	-0.73	-0.77	-0.81	-0.85	-0.90	-0.96
55	-0.54	-0.55	-0.57	-0.59	-0.61	-0.64	-0.67	-0.70	-0.73	-0.77	-0.81	-0.85	-0.90
60	-0.52	-0.54	-0.55	-0.57	-0.59	-0.61	-0.64	-0.67	-0.70	-0.73	-0.76	-0.80	-0.85
65	-0.51	-0.52	-0.54	-0.55	-0.57	-0.59	-0.61	-0.63	-0.66	-0.69	-0.72	-0.75	-0.79
70	-0.49	-0.51	-0.52	-0.53	-0.55	-0.56	-0.58	-0.60	-0.62	-0.65	-0.68	-0.71	-0.74
75	-0.48	-0.49	-0.50	-0.51	-0.52	-0.54	-0.55	-0.57	-0.59	-0.61	-0.63	-0.66	-0.68
80	-0.47	-0.47	-0.48	-0.49	-0.50	-0.51	-0.52	-0.54	-0.55	-0.57	-0.59	-0.61	-0.63
85	-0.45	-0.46	-0.46	-0.47	-0.48	-0.49	-0.50	-0.51	-0.52	-0.53	-0.54	-0.56	-0.57
90	-0.44	-0.44	-0.45	-0.45	-0.46	-0.46	-0.47	-0.47	-0.48	-0.49	-0.50	-0.51	-0.52

Almond irrigation scheduling handout

Almond Irrigation Scheduling

Using Midday Stem Water Potential to Refine Irrigation Scheduling in Almond

Bruce Lampinen (Department of Plant Science, UC Davis)

There are several advantages to using midday stem water potential as an adjunct to monitoring soil moisture or using evapotranspiration based irrigation scheduling. Measuring soil moisture gives you an idea what is going on in only a limited volume of soil where your measurement device is placed. It can be difficult to decide where to monitor soil moisture since tree roots can be quite deep and variable depending on irrigation system design (i.e. variable roots under drip irrigation) and method of operation (i.e. deep versus shallow irrigations). Using evapotranspiration based scheduling alone can lead to problems if you do not know the soil moisture conditions at the beginning of the season, your irrigation system application efficiency is lower than you estimate, or your estimates of crop water use are incorrect. Midday stem water potential can be used as an adjunct to either soil or evapotranspiration based irrigation scheduling to help refine your irrigation scheduling. The advantage to using midday stem water potential is that it integrates soil factors for the entire tree root system as well as environmental factors giving you an accurate picture of the level of stress the tree is experiencing. Ideally, a combination of evapotranspiration, soil and plant based measurements should be used.

Pressure chamber basics*

Water in a plant is under tension. By bagging a leaf low on the tree at least 15 minutes before sampling, you can allow it to equilibrate with the water potential in the stem. Then, you can cut off the leaf and place it in a pressure chamber with the petiole protruding out. As you pressurize the cylinder, a point will be reached where the water will just begin coming out of the cut surface. At this point, a reading of the dial gauge will give the midday stem water potential. Since the midday stem water potential is measuring a tension, the value is normally expressed as a negative value with a fully watered almond tree being somewhere near -0.6 to –1.0 MPa depending on environmental conditions. A moderately stressed almond tree might have a midday stem water potential of –1.0 to –1.5 MPa).

Procedure to measure midday stem water potential

1) Readings should be taken approximately weekly between 1 and 3 pm.
2) At least 15 minutes before taking readings, place aluminum foil covered plastic bags over mature, lower canopy shaded leaves on approximately 10 trees per orchard. The number of trees to sample depends on accuracy desired, soil/irrigation variability in orchard etc.
3) Remove leaves from tree one at a time and immediately place in pressure chamber (leaving leaf inside aluminum foil covered plastic bag)
4) Pressurize until you see water just begin to come out of the cut end. If you go past the endpoint and see excessive water bubbling out, back off and re-pressurize to determine the endpoint.
5) Record reading and move on to next tree.
6) Record the time, temperature and relative humidity (if available) at the time the readings were taken.

The table below gives you midday stem water potential values in MPa for a fully watered almond tree under varying conditions of temperature and relative humidity. The green zone indicates typical range for the Central Valley of California.

Relative Humidity (%)	Temperature (°C)												
	20	22	24	26	28	30	32	34	36	38	40	42	44
10	-0.66	-0.70	-0.73	-0.77	-0.82	-0.87	-0.92	-0.98	-1.05	-1.13	-1.21	-1.30	-1.39
15	0.65	0.68	0.71	0.75	0.80	0.84	0.89	0.95	1.02	1.09	1.16	1.25	1.34
20	-0.63	-0.66	-0.70	-0.73	-0.77	-0.82	-0.87	-0.92	-0.98	-1.05	-1.12	-1.20	-1.28
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30	-0.61	-0.63	-0.66	-0.69	-0.73	-0.77	-0.81	-0.86	-0.91	-0.97	-1.03	-1.10	-1.17
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45	-0.56	-0.58	-0.61	-0.63	-0.66	-0.69	-0.72	-0.76	-0.80	-0.85	-0.90	-0.95	-1.01
50	-0.55	-0.57	-0.59	-0.61	-0.64	-0.66	-0.70	-0.73	-0.77	-0.81	-0.85	-0.90	-0.96
55	-0.54	-0.55	-0.57	-0.59	-0.61	-0.64	-0.67	-0.70	-0.73	-0.77	-0.81	-0.85	-0.90
60	-0.52	-0.54	-0.55	-0.57	-0.59	-0.61	-0.64	-0.67	-0.70	-0.73	-0.76	-0.80	-0.85
65	-0.51	-0.52	-0.54	-0.55	-0.57	-0.59	-0.61	-0.63	-0.66	-0.69	-0.72	-0.75	-0.79
70	-0.49	-0.51	-0.52	-0.53	-0.55	-0.56	-0.58	-0.60	-0.62	-0.65	-0.68	-0.71	-0.74
75	-0.48	-0.49	-0.50	-0.51	-0.52	-0.54	-0.55	-0.57	-0.59	-0.61	-0.63	-0.66	-0.68
80	0.47	0.47	0.48	0.49	0.50	0.51	0.52	0.51	0.55	0.57	0.59	0.61	0.63
85	-0.45	-0.46	-0.46	-0.47	-0.48	-0.49	-0.50	-0.51	-0.52	-0.53	-0.54	-0.56	-0.57
90	0.44	0.44	0.45	0.45	0.46	0.46	0.47	0.47	0.48	0.49	0.50	0.51	0.52

Interpretation and uses of midday stem water potential data

Mature trees

By keeping the midday stem water potential values near the fully watered baseline, you can assure that you do not get into deficit conditions. However, it is usually advantageous to allow the midday stem water potential to fall at least 0.1 to 0.2 MPa below the baseline before beginning irrigation to assure that you are not over-irrigating. After irrigation it is best to approach but not reach the baseline. This is particularly true in areas where a water table is present.

By taking readings before and after an irrigation event, you can better adjust the timing of system operation. If you do not approach the baseline after an irrigation, you should most likely irrigate for a longer period during the next cycle.

Hull rot

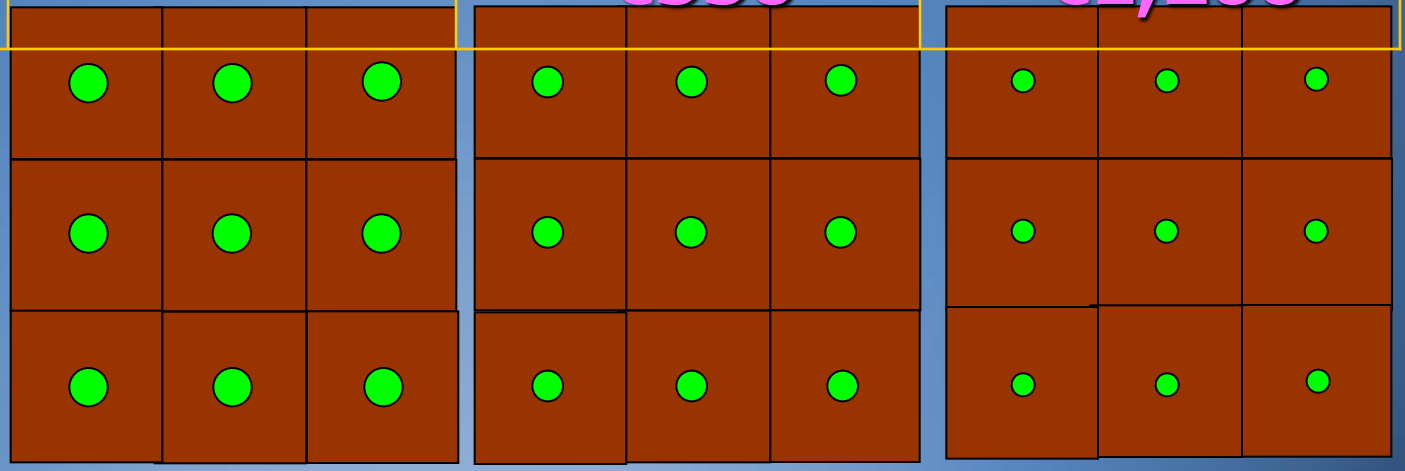
Previous work has suggested that moderate water deficits during hull split may lead to a decreased incidence of hull rot. Research suggests that a midday stem water potential of about -1.4 to -1.7 MPa during hullsplit followed by a return to full irrigation can lead to decreased incidence of hull rot without impacting yields

Young trees

For young almond trees, where maximum vegetative growth may be desirable to fill in the canopy rapidly, the average value of midday stem water potential should be close to the baseline (irrigate at -

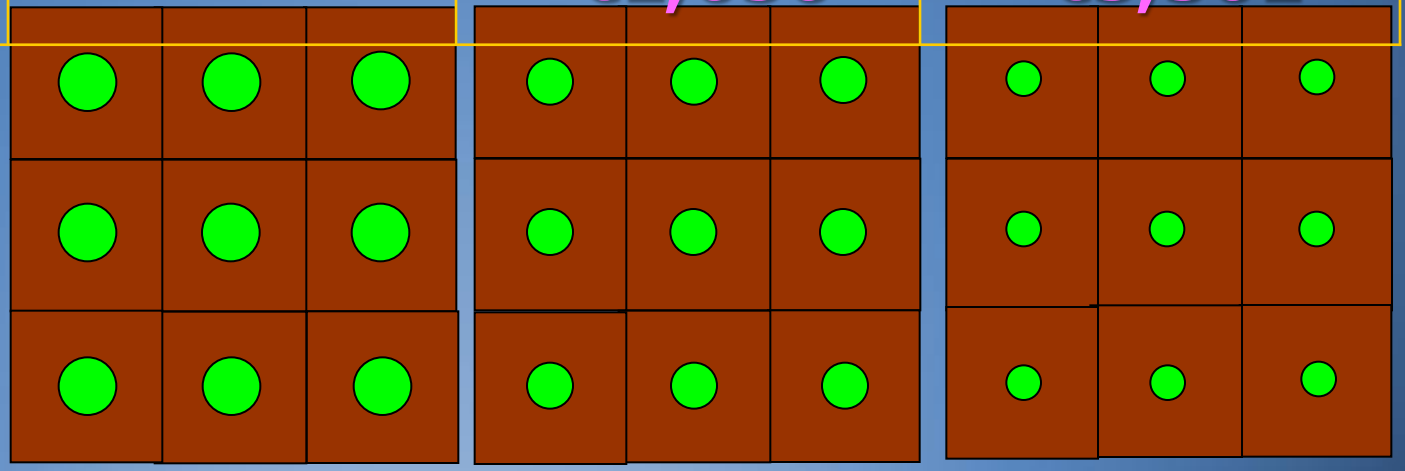
After two years at seasonal average midday stem water potential of:

	-0.8 Mpa	-1.2 MPa	-1.6 MPa
Yield (MT/ha)	0.56	0.45	0.34
Cum. yield	0.56	0.45	0.34
Cum. Euros	€2751	€2201	€1,800
Per ha loss		-€550	-€1,200



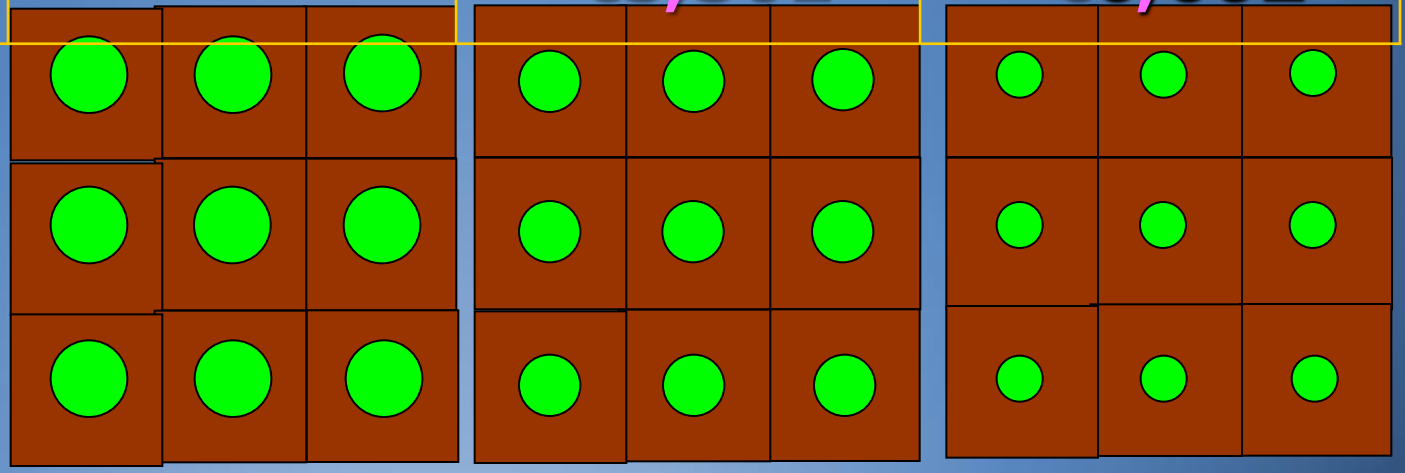
After three years at seasonal average midday stem water potential of:

	-0.8 Mpa	-1.2 MPa	-1.6 MPa
Yield (MT/ha)	0.45	0.36	0.27
Cum. yield	1.12	0.90	0.67
Cum. Euros	€8,252	€6,602	€4,951
Per ha loss		-€1,650	-€3,301



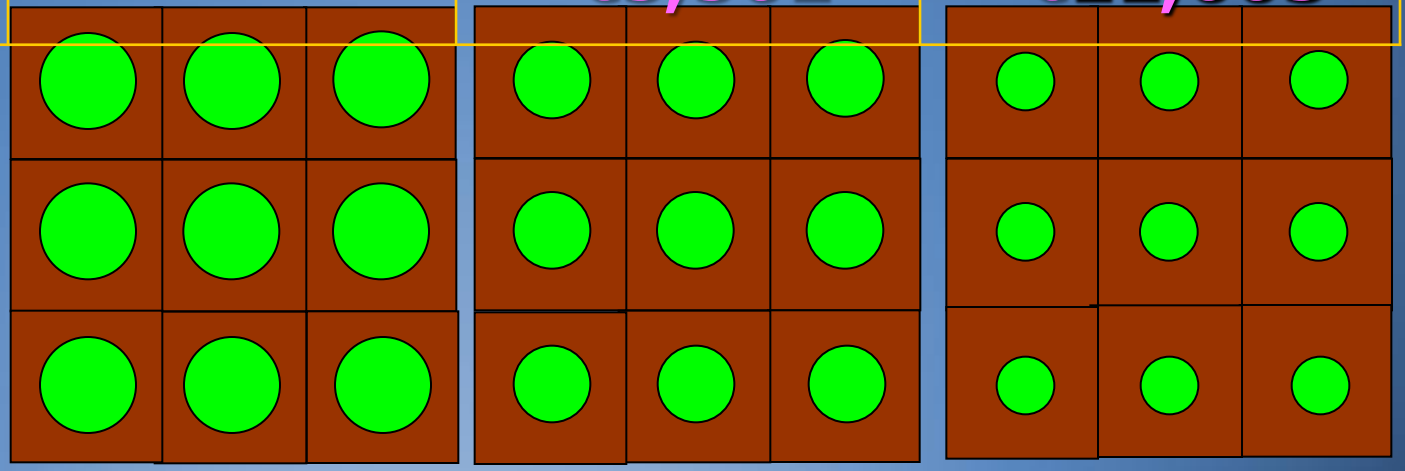
After four years at seasonal average midday stem water potential of:

	-0.8 Mpa	-1.2 MPa	-1.6 MPa
Yield (MT/ha)	1.68	1.35	1.01
Cum. yield	3.37	2.69	2.02
Cum. Euros	€16,504	€13,203	€9,902
Per ha loss		-€3,301	-€6,602



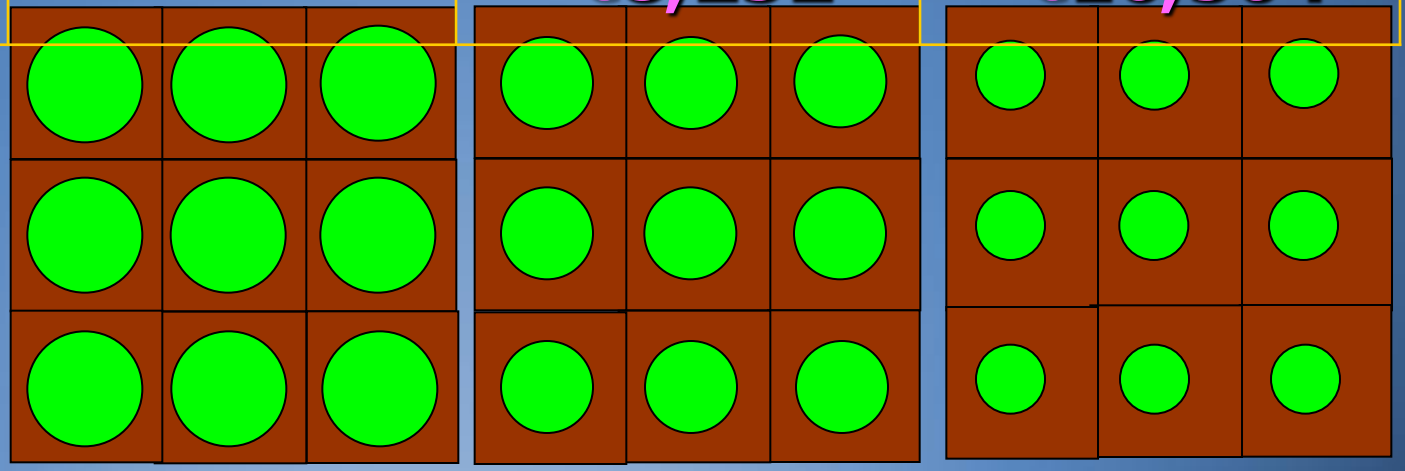
After five years at seasonal average midday stem water potential of:

	-0.8 Mpa	-1.2 MPa	-1.6 MPa
Yield (MT/ha)	2.25	1.35	1.01
Cum. yield	3.37	2.69	2.02
Cum. Euros	€27,507	€22,005	€16,504
Per ha loss		-€5,501	-€11,003



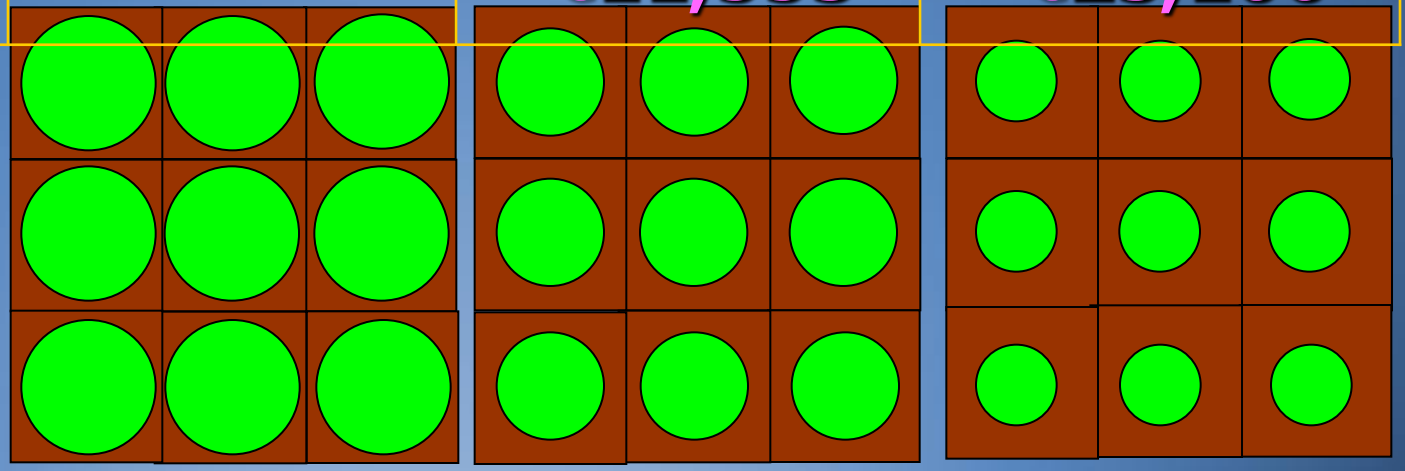
After six years at seasonal average midday stem water potential of:

	-0.8 Mpa	-1.2 MPa	-1.6 MPa
Yield (MT/ha)	2.81	2.25	1.68
Cum. yield	8.42	6.74	5.05
Cum. Euros	€41,260	€33,008	€24,756
Per ha loss		-€8,252	-€16,504



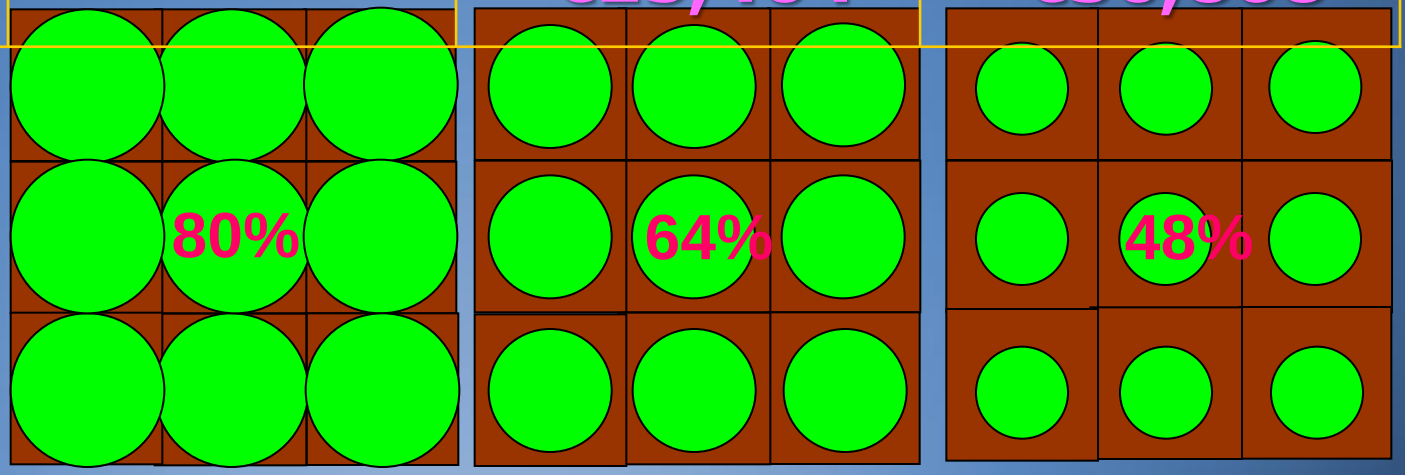
After seven years at seasonal average midday stem water potential of:

	-0.8 Mpa	-1.2 MPa	-1.6 MPa
Yield (MT/ha)	3.37	2.69	2.02
Cum. yield	8.42	6.74	5.05
Cum. Euros	€57,764	€46,211	€34,659
Per ha loss		-€11,553	-€23,106



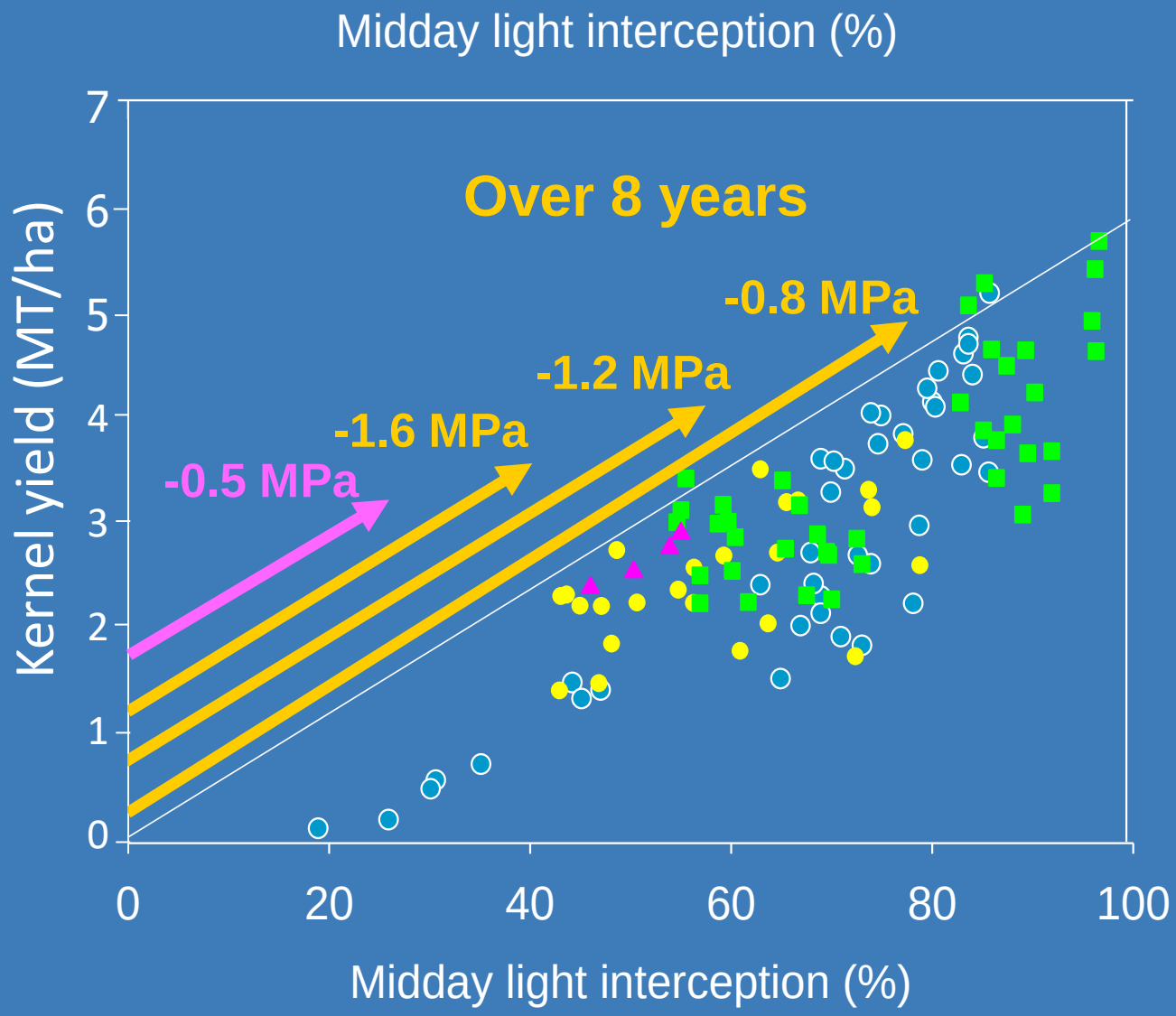
After eight years at seasonal average midday stem water potential of:

	-0.8 Mpa	-1.2 MPa	-1.6 MPa
Yield (MT/ha)	3.93	3.14	2.36
Cum. yield	15.72	12.57	9.43
Cum. Euros	€77,019	€61,615	€30,808
Per ha loss		-€15,404	-€30,808



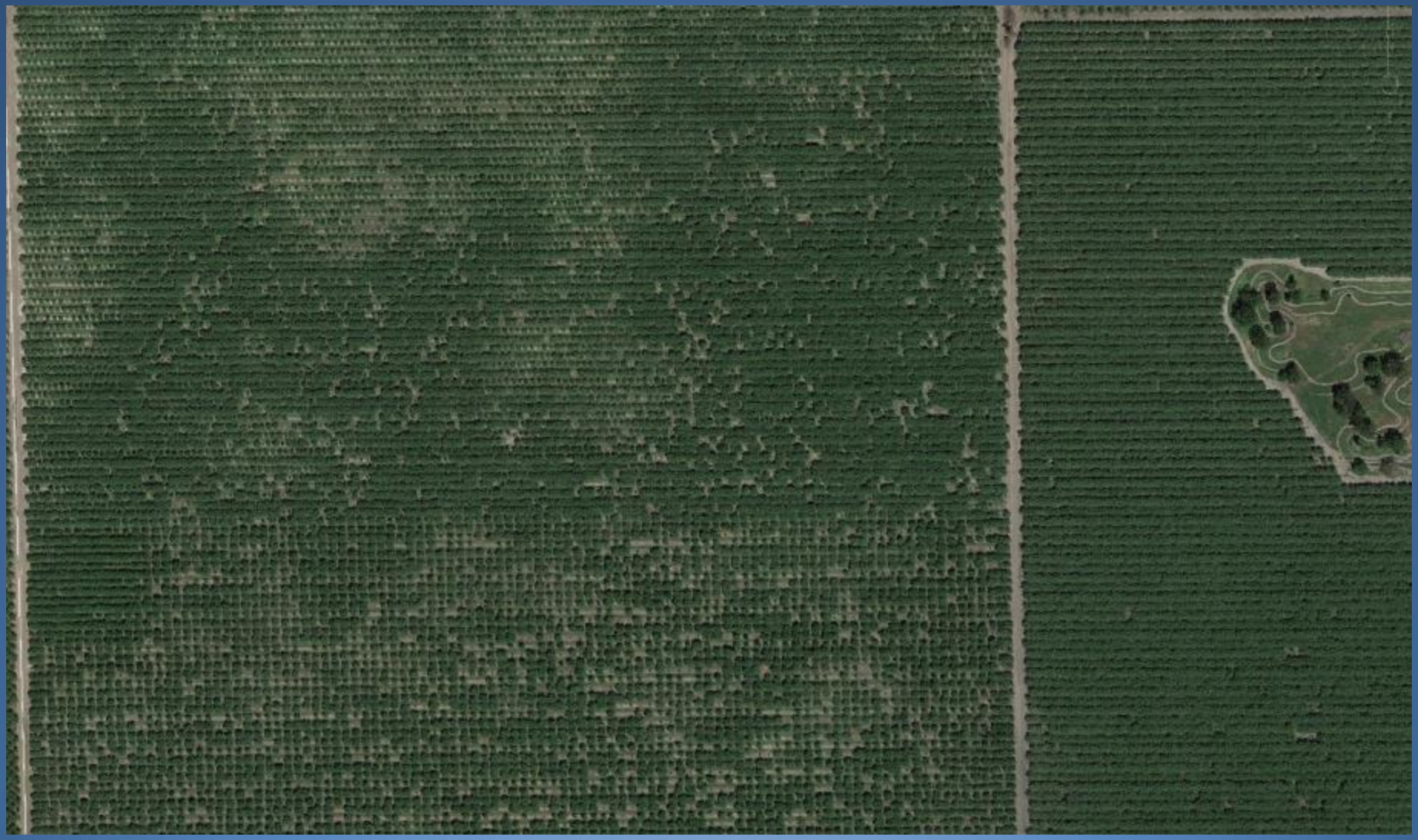
Summary of potential revenue loss from stress during canopy development phase

Time period	Loss per hectare for each 0.1 MPa of stress	Loss on 40 hectares for each 0.1 MPa of stress	Loss on 40 hectares for 0.4 MPa of stress
1 year	€480	€19,200	€76,800
8 years	€3,840	€153,600	€614,400



Approximately 5% loss in rate of canopy development per 0.1 MPa of seasonal average midday stem water potential deficit

It is difficult to put on more than 1400 mm of water on most soils without causing tree health problems particularly during high evaporative demand periods in July and August



More variation in tree size when over-irrigating
(This is the biggest problem for our growers)

Summary of available yield versus applied water trials in California and Australia suggest that production potential is 0.00315 MT/mm water applied so yield potential is about 2 MT/ha with 650mm rainfall under rain-fed conditions

PAR interception	Applied water (mm)	Yield potential (MT/ha)
10	178	0.560
20	356	1.121
30	533	1.681
40	711	2.242
50	889	2.802
60	1067	3.363
70	1245	3.923
80	1422	4.483
90	1600	5.044

39% interception (1.6 to 2.2 MT/ha potential

50% interception (2.2 to 2.8 MT/ha potential

80% interception (3.9 to 4.5 MT/ha potential

90% interception (4.4 to 5.0 MT/ha potential

39% interception (1.6 to 2.2 MT/ha potential

50% interception (2.2 to 2.8 MT/ha potential

80% interception (3.9 to 4.5 MT/ha potential

90% interception (4.4 to 5.6 MT/ha potential

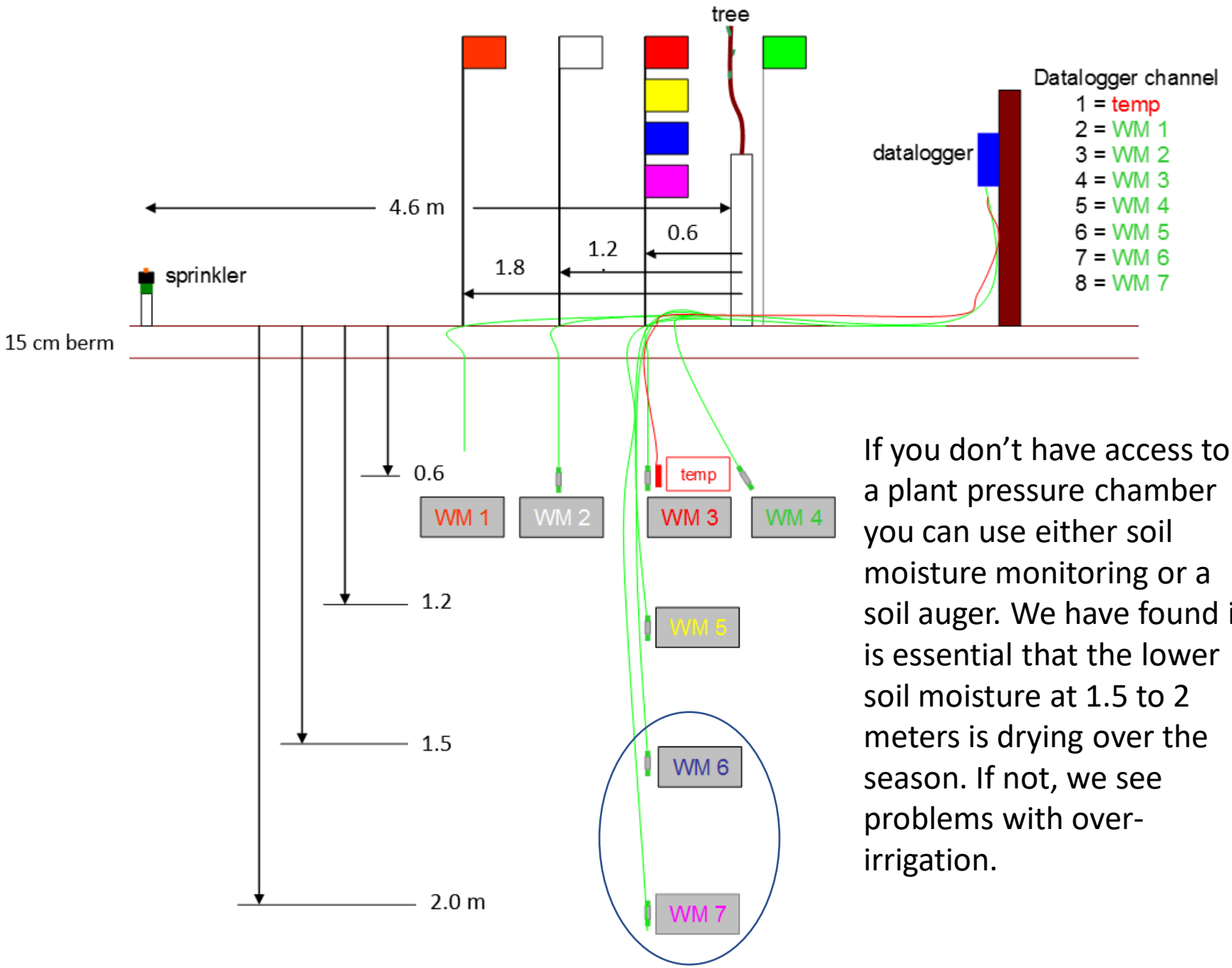
Dryland trees in Spain

20% interception (0.6 to 1.1 MT/ha potential

25% interception (0.8 to 1.3 MT/ha potential

30% interception (1.1 to 1.6 MT/ha potential

30% interception (1.1 to 1.6 MT/ha potential



If you don't have access to a plant pressure chamber you can use either soil moisture monitoring or a soil auger. We have found it is essential that the lower soil moisture at 1.5 to 2 meters is drying over the season. If not, we see problems with over-irrigation.

http://pmsinstrument.com/

http://www.soilmoisture.com

Conclusions for almond irrigation

Canopy growth is directly proportional to MSWP (unless trees are wetter than the baseline)

Pressure chamber is essential to ensure good canopy expansion during development phase

Water use and yield potential are directly related to canopy growth

Common wisdom on why almonds need to be pruned

- Manage light distribution through canopy
  Pruning exacerbates these problems leading to increased interior shading
- Rejuvenate canopy to maintain productivity
  No evidence this is the case- no benefit over 21 years
- Decrease disease susceptibility
  Uncertain- if this is the case it has not been enough to improve productivity
- Manage alternate bearing
  Perhaps, but no data to support this
- Maintain tree size
  Perhaps, but comes at the expense of productivity

Summary on pruning

- The less you prune trees during the canopy development phase, the quicker you will come into production
- There is no data to suggest that there is a need to prune mature almond trees on an annual basis
- Pruning does not sustain productivity in the short or long term (as long as 21 years)
- You should only prune to:
  - ✓ Improve safety for workers
  - ✓ Improve visibility of trunks to decrease chance of damaging trees with shaker
  - ✓ Remove dead or diseased wood
  - ✓ Improve ability to dry nuts in densely shaded orchards (mechanical hedging)
- In conclusion, every pruning cut you make decreases yield (unless it is a dead branch you cut off)

Summary on Canopy PAR interception/yield potential

- The most productive almond orchards in our studies can produce about 5.6 mt/ha of kernel (and the average about 4.5)
- Across the range of planting densities in our studies (80-202 trees per acre) at maturity there do not appear to be any clear density related differences in production potential
- There is some indication that higher density plantings than those in our study may potentially be able to intercept more PAR over the course of the day for a given level of midday PAR interception
- However, keeping productivity up at this density will require breeding and training work to create smaller tree structures that do not require continual hedging or training to keep trees within size range of over the row harvesters as well as new machinery for harvest and field operations

Sources of information on almond production

Fruit and Nut Research and Information Center information on almonds (UC Davis Plant Sciences Department)
http;//fruitsandnuts.ucdavis.edu/datastore/?ds=391&reportnumber=612&catcol=2806&categorysearch=Almond

Almond Almanac and 2018 Almond Research update are available at the site below
http://www.almonds.com/processors/resources/almond-almanac

UC Davis Almond Short Course November 2019
(Visalia, California Nov. 5-7, 2019)
https://ucanr.edu/sites/almondshortcourse/

2020 Principles of Fruit and Nut Tree Growth, Cropping and Management
(UC Davis March 23-April 2, 2020)
http://fruitandnuteducation.ucdavis.edu/education/principles/

Almond rootstocks
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Thank you!