UC DAVIS
DEPARTMENT OF PLANT SCIENCES
College of Agricultural and Environmental Sciences

Pistachio Botany and Physiology

Louise Ferguson and Giulia Marino

Outline

- Climate
- Production Management by chill and heat accumulation
  - Dormancy
  - In-season Phenology
- Soil and Water Quality
- Growth and Bearing Habit
  - Training, Hand and Mechanical Pruning but why we can mechanically prune
- Alternate Bearing
  - Within branch phenomenon
  - Greatly affected by rootstock

Pistacia vera

Botany: origins

- **Temperature deciduous tree**
- ***Pistacia* species native to areas from 40⁰ to 70⁰ latitude**
- ***P. vera* is from Western Asia and Asia Minor**
- ***P. atlantica* originated in Iranian plateaus**
- ***P. integerrima* originated in NW Himalayan region of India**

Dioecious

- **Definition: Separate houses**
- **Bloom overlap critical**

Male

Female

Botany: growth characteristics

- 25-35 feet (7.6-10.6 meters) tall
- Apically dominant growth habit
- Long juvenility
- Bears crop on one-year-old wood
- Alternate bearing scion
  - that is mitigated by rootstock
- Physical adaptations for drought, salinity, temperature
  - roots, leaves, carbohydrate storage capacity


8 -10m
R2
T9
I
1.5 M
7 M

Female Inflorescence

Phase 0

Swollen winter Bud

Phase 1

initial Bud break

Phase 2

Stigmas exposure

Phase 3

Stigmas desiccation (Initial)

Phase 4

Stigmas desiccation (End)

Phase 5

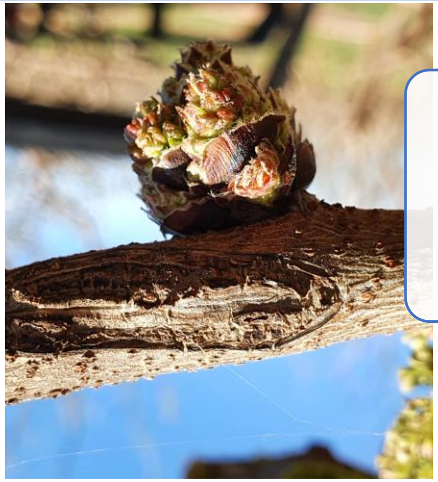
Ovary Growth

Male Inflorescence

Phase 0

Swollen winter Bud

Phase 1 (Initial)

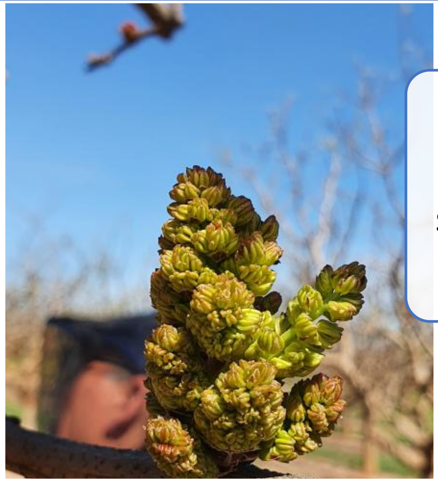


Initial Bud break

Phase 1 (Final)

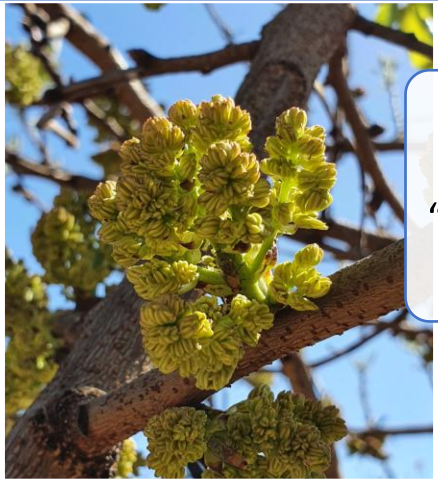
Final Bud break

Phase 2



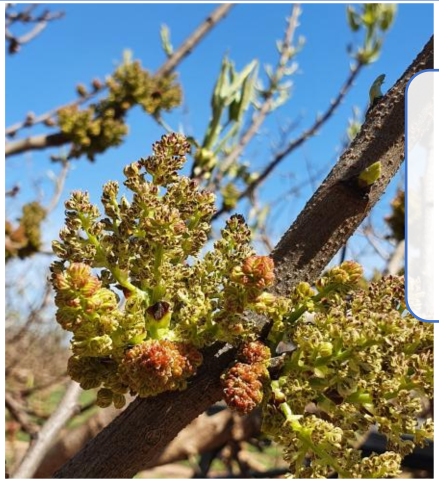
“Branch” separation

Phase 3



Fully “Branched”

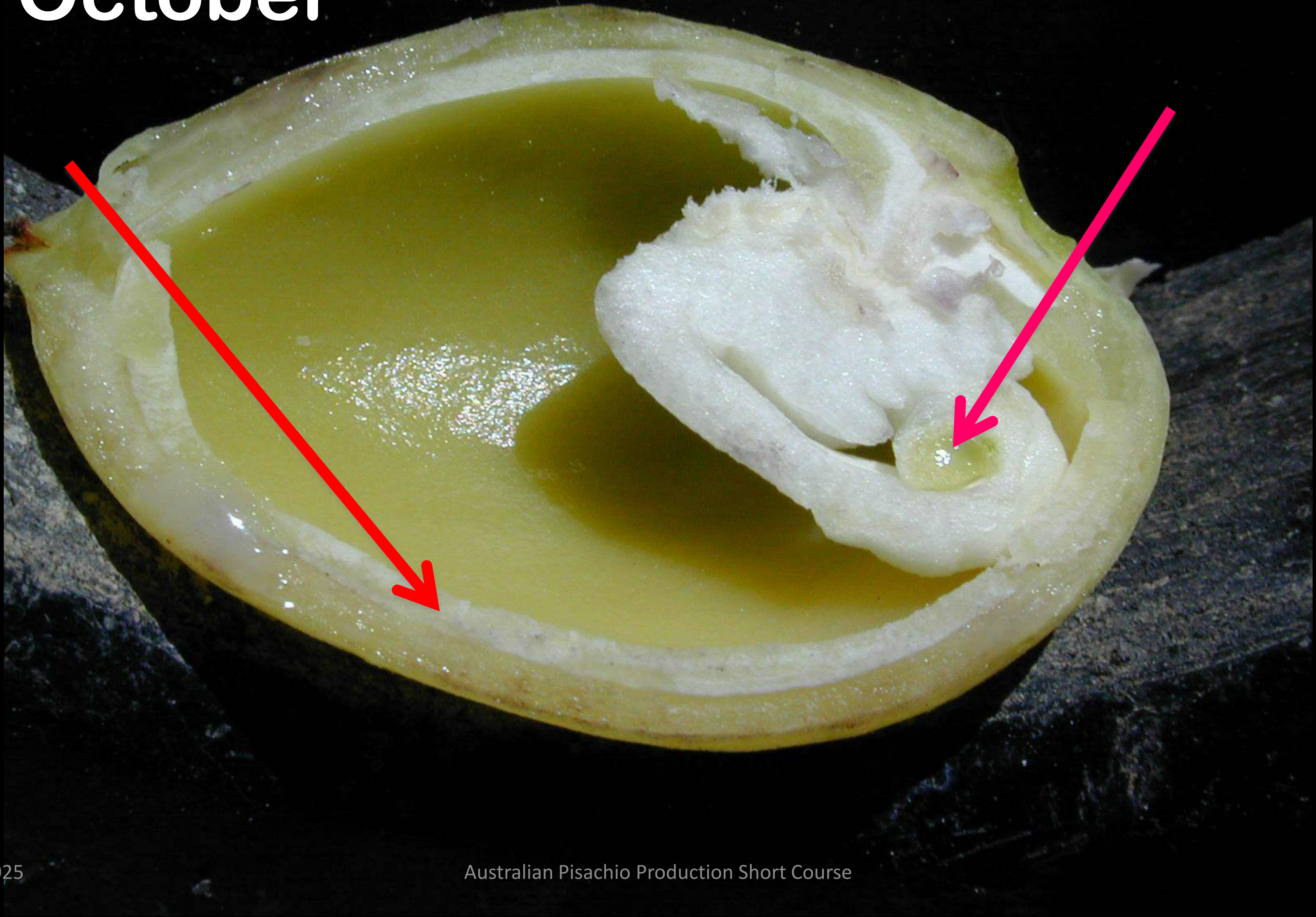
Phase 4



Pollen Release


Photo: L. Ferguson

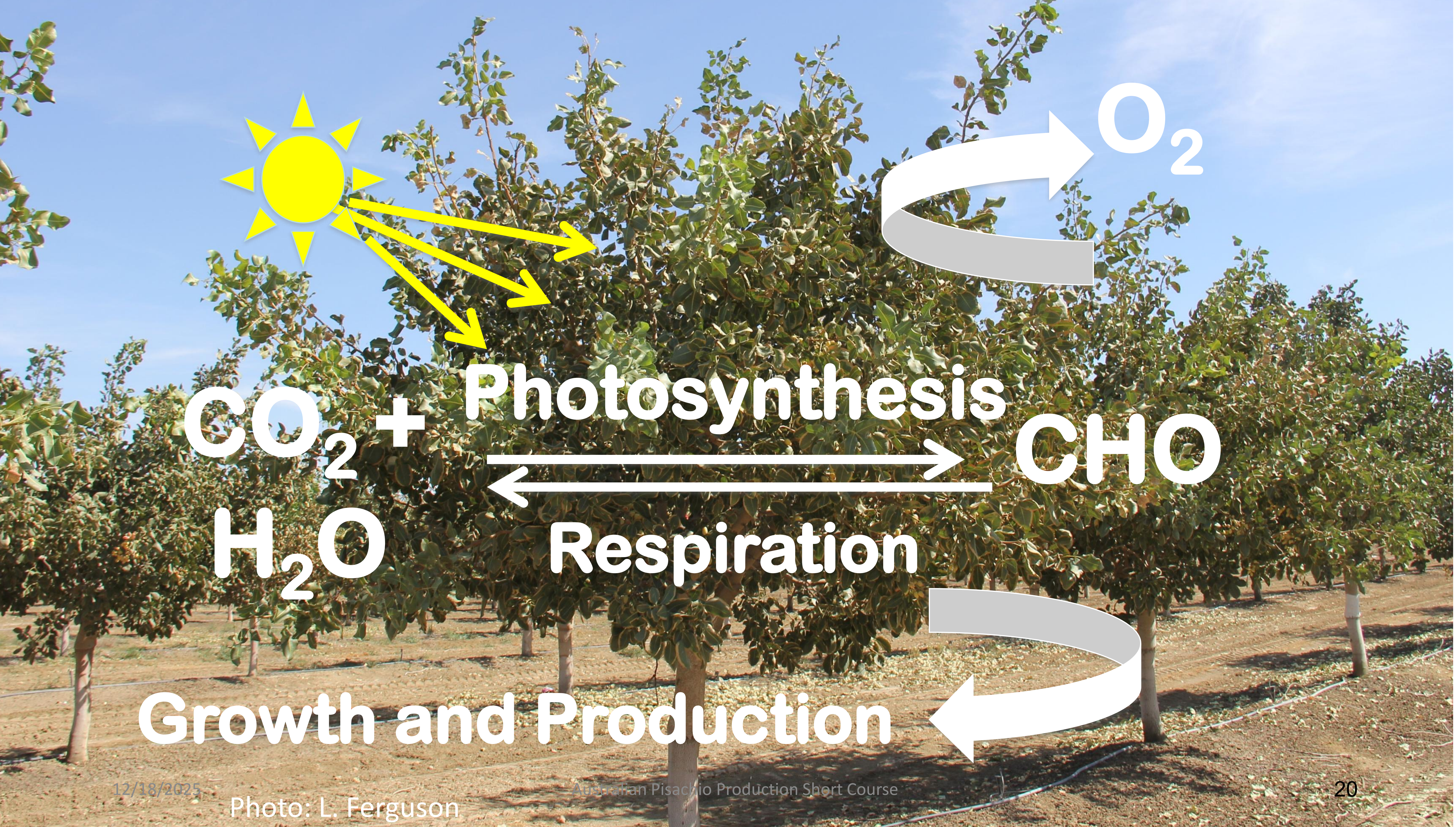
October



November

December

January

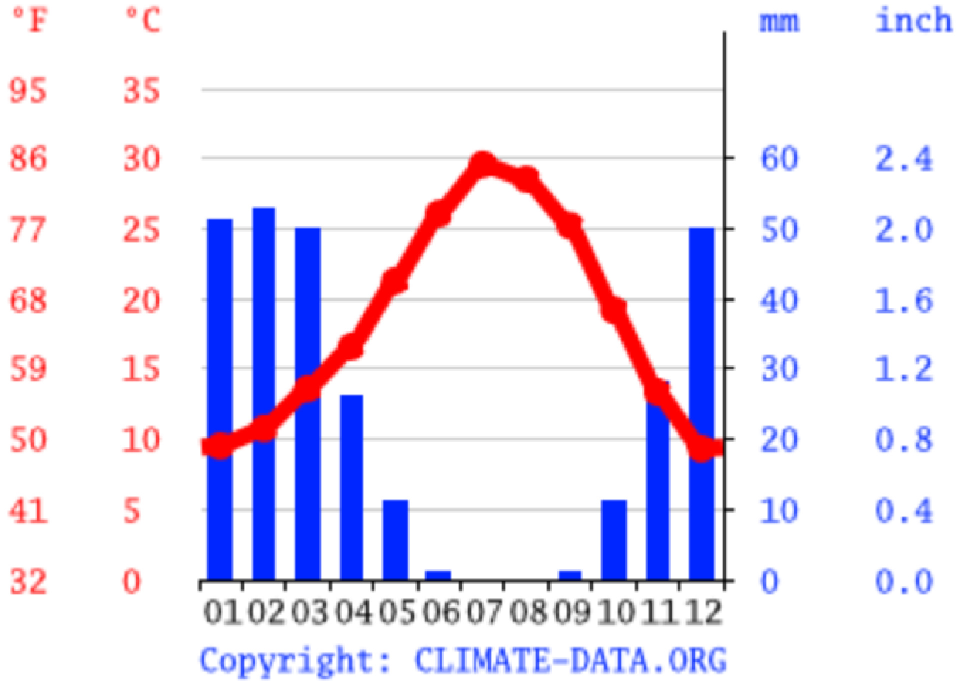

O_2
Photosynthesis
CO_2 +
H_2O
CHO
Respiration
Growth and Production
Photo: L. Ferguson

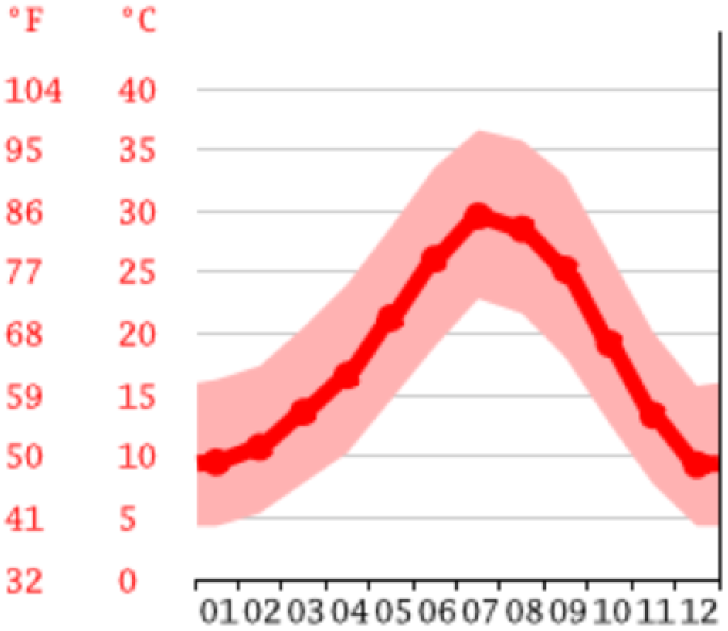
Requirements for Pistachio Production:

- Disease limitations
  - ***Verticillium dahliae, Bostrysphaeria, Anthracnose***
- **Climate**
  - **Winter dormancy, in season growth**
- **Soil and water quality and quantity**
- **Infrastructure for production and processing**
- **Resources for research, education and crop improvement**

BAKERSFIELD CLIMATE (UNITED STATES OF AMERICA)

DATA AND GRAPHS FOR WEATHER & CLIMATE IN BAKERSFIELD





Critical Temperatures:

- Critical heat temperatures unknown: when photosynthesis ceases
  - Literature suggests 77-86º F (25-30º C)
- Critical cold temperatures largely unknown
  - Rootstock more sensitive than the scion
  - 11 nights between 4º and 11º F (-15.5 to -12º C)in 1990
    - *P. integerrima*: 41% mortality
    - *P. atlantica*: 0% mortality
    - *P. atlantica x P. integerrima*: 0% mortality


Goose Lake Slough: May 2009

Winter Juvenile Tree Dieback: Frost Damage

Little research-backed data, observations

Risk factors:

- ***P. integerrima*** **rootstocks: PGI or UCBI**
- **young, non-early bearing vigorous trees going into the fall**
- **wet soils**
- **sodium affected soils (due to poor water movement from dispersed soils)**

Temperature Requirements: Dormancy

- **Temperature limits are poorly defined:**

- **Cool winters with temperatures in the 5-10*C ranges**
  - **No hard freezes**
  - **No late or early freezing temperatures: climate change**
- **Chill hours required for successful dormancy (Beede 2005)**
  - **Kerman: > 750 hours @ (0 - 7.2 ^{o} C)**
  - **Peters: > 900 hours @ (0 - 7.2 ^{o} C)**

- **Recent research is better defining temperature requirements (Pope 2014)**
  - **Using weighted models that account for higher and lower dormant temperatures**
  - **Chill portions**
    - **Kerman > 54-58**
    - **Peters > 58-65**
    - **Theoretical and not verified in California**

Sirora (Australia): 60 chill portions
(Zhang and Taylor, 2011)

Does it matter which model is used?

What is known about chill models

Information from controlled experiments	Chilling Hours	Utah	Utah+	Dynamic Model	
Depends on temperature	+	+	+	+	
Daily temperature cycle	+	+	+	+	
Weighted temperatures	-	+	+	+	
Continuous weights	-	-	-	+	
Warm temperatures -	-	+	-	+	
Moderate temperatures +	-	-	-	+	
Two-phase process	-	-	-	+	

Luedeling et al. Erwerbsobstbau (submitted).

Dormancy and bloom temperatures

- **Dormancy: when growth does not occur in living plants:**
  - **Endodormancy: when growth does not occur due to conditions within the plant:**
    - **dormancy requirement, chill accumulation has been met**
  - **Ecodormancy: when growth does not occur due to conditions external to the plant:**
    - **released when temperatures are sufficient for bloom: heat accumulation**

  - **Investigating limits of chill accumulation which will require more spring heat**
    - **Can possibly be used to determine when dormancy breaking chemicals might be needed**

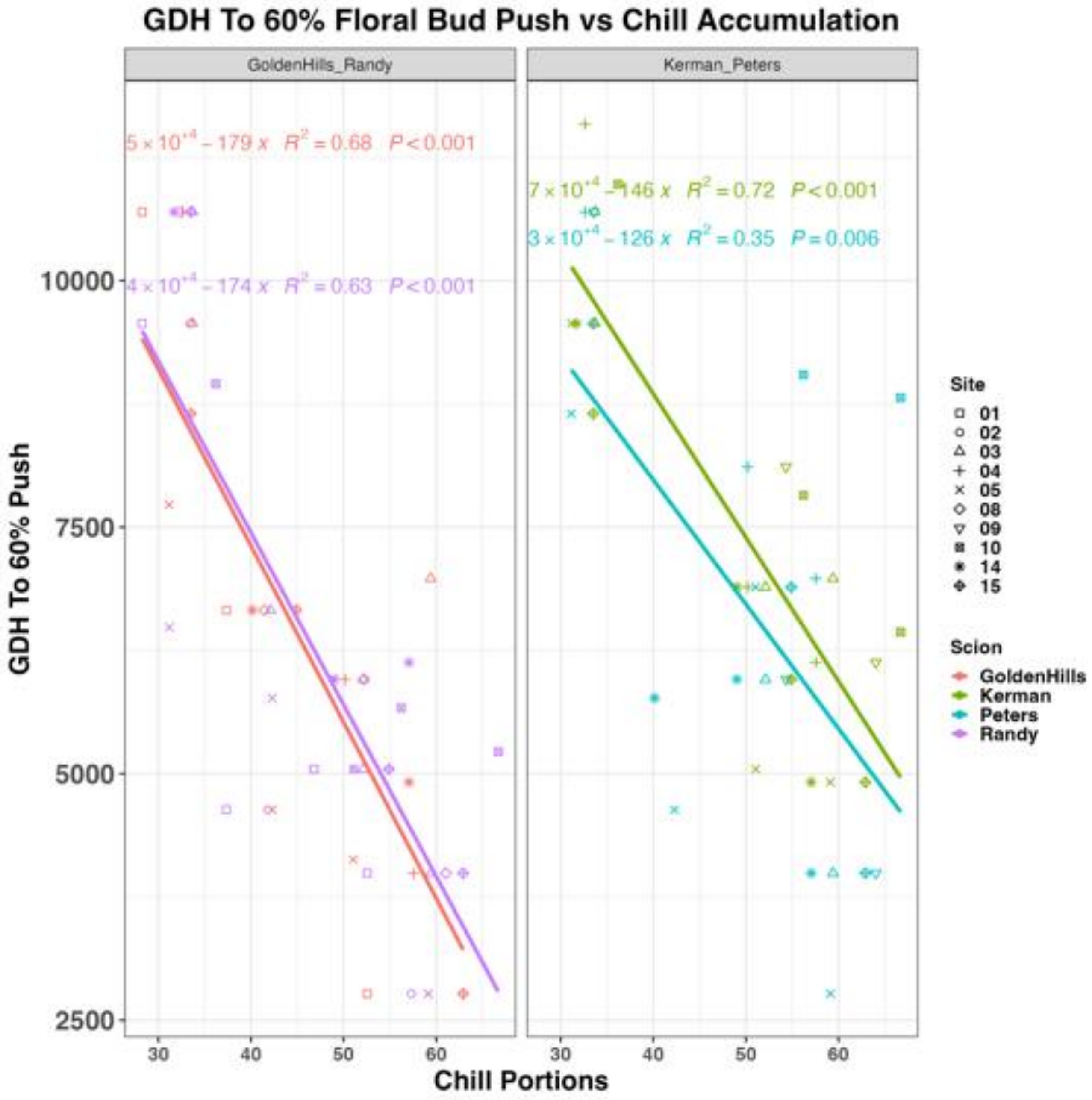
Integrating winter chill and spring heat effects on

Chill + Heat requirements of male and female cultivars for bloom:

Collected year old shoots at different chill portions and forced in greenhouse to determine how much more heat (GDH) was required for bloom:

Demonstrated which male and female pairs were more synchronous:

Demonstrated lower limit of chill required for bloom and when dormancy breaking agents are required.

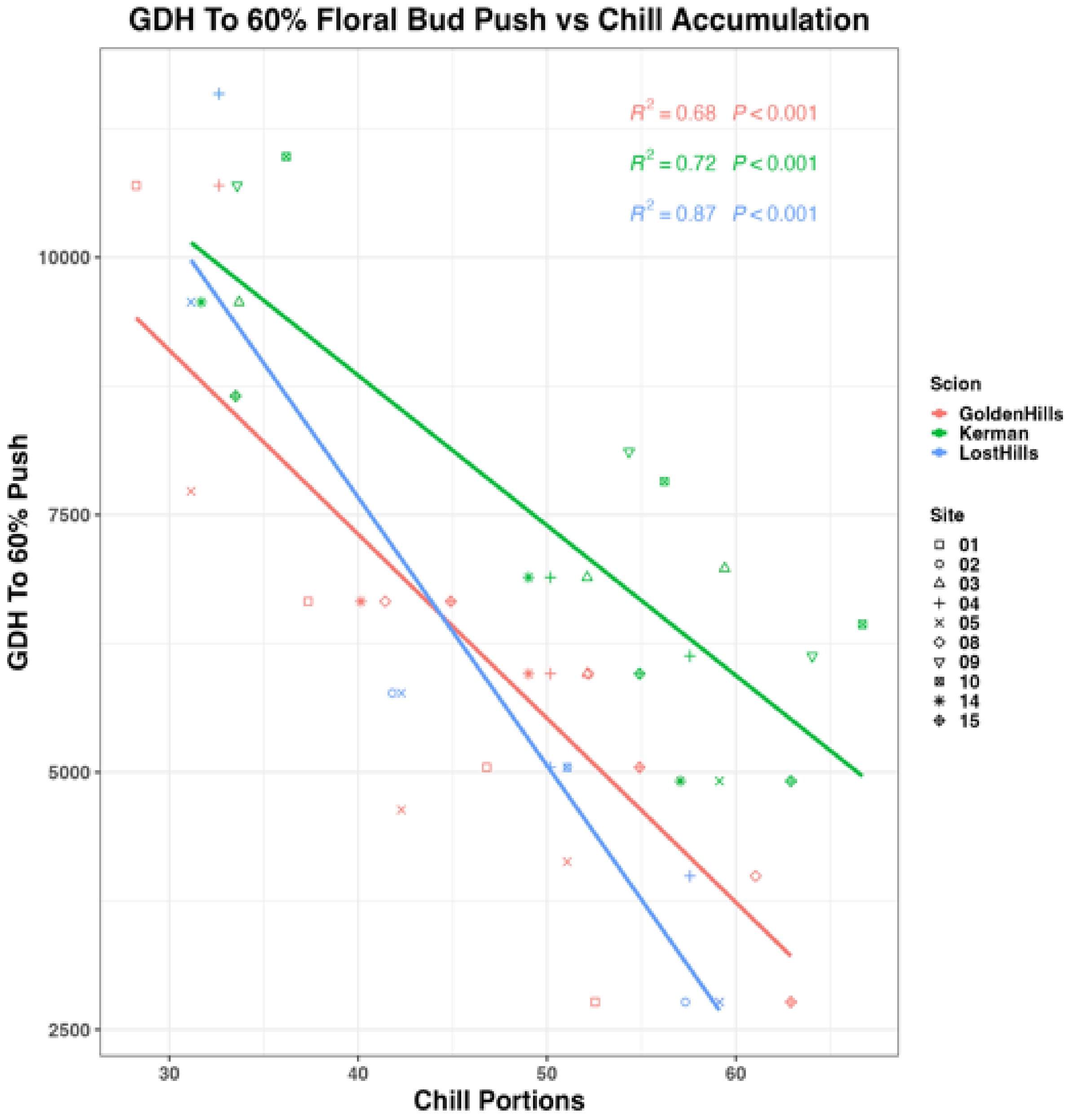


Chill + Heat requirements for female cultivar bloom:

Collected year old shoots at different chill portions and forced in greenhouse to determine how much more heat (GDH) was required for bloom:

Demonstrated chill requirements of female cultivars:

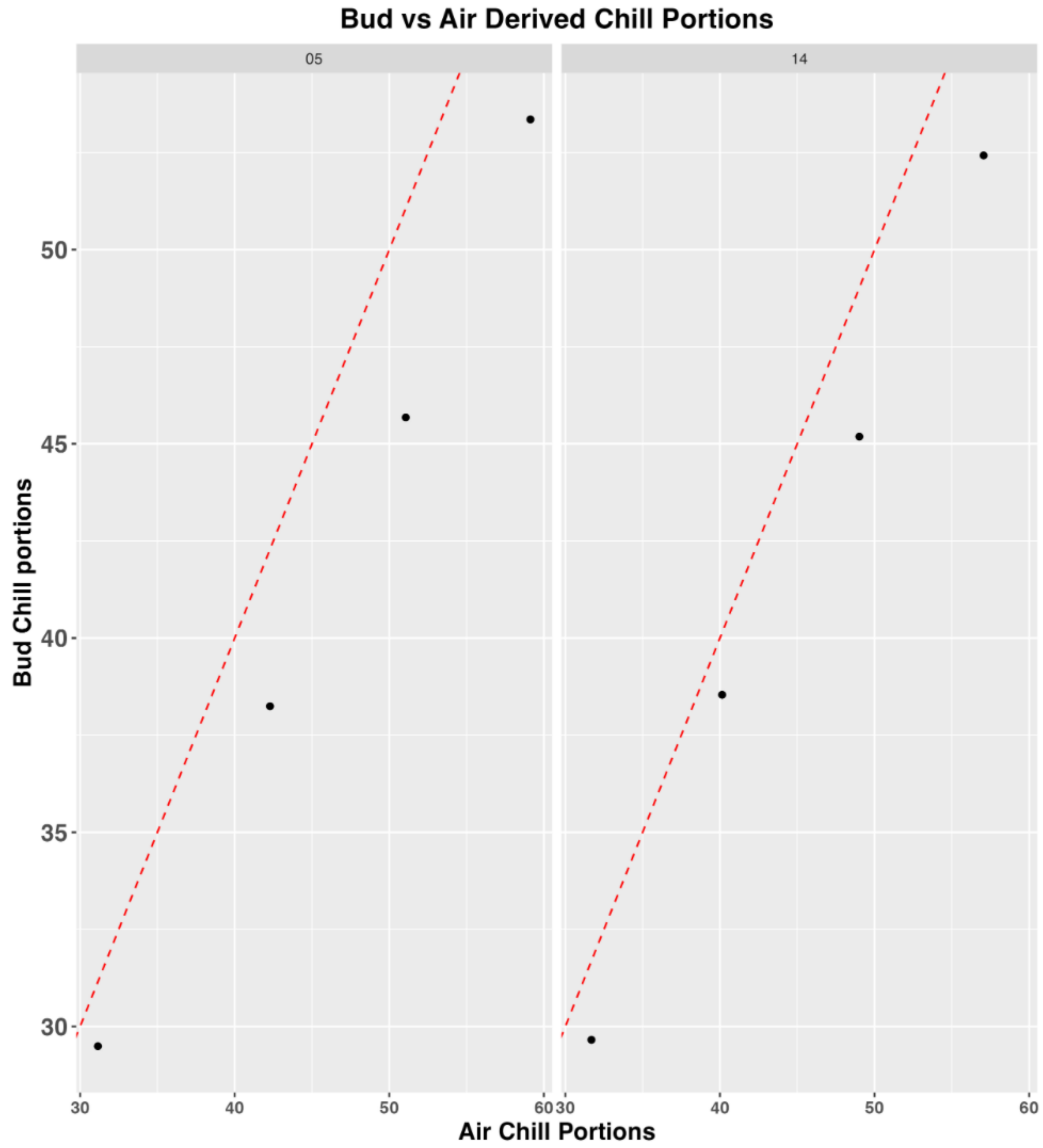
- Kerman requires more heat to bloom at 50 chill portions than either Golden or Lost Hills



Effect of winter light on bud temperatures, dormancy and bloom :

Measured bud and ambient air temperatures and collected year-old shoots at different chill portions and forced in greenhouse to determine how much more heat (GDH) was required for bloom at different chill accumulations:

Demonstrates bud chill portion accumulation was lower than air chill portion accumulation and that basing chill portion accumulation on air temperatures will underestimate chill portion accumulation.



All folders are up to da

Now Giulia will discuss monitoring to capture these temperature differences…

Low winter chill + reduction of fog

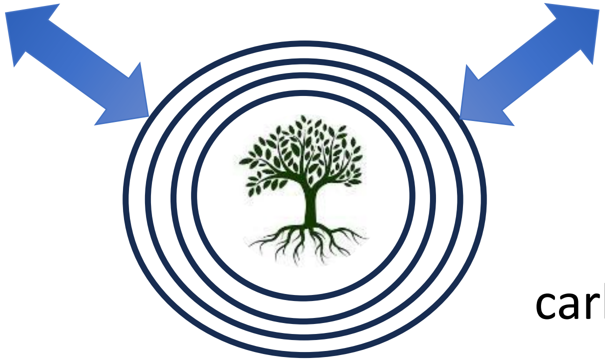
Objectives and hypotheses

FUNDAMENTAL

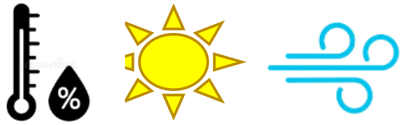
Improve the accuracy of chill estimation calculations

Meteorological approach

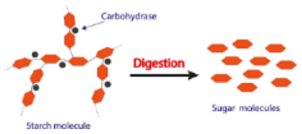
Physiological approach



Tree temperature as predictor of chill accumulation



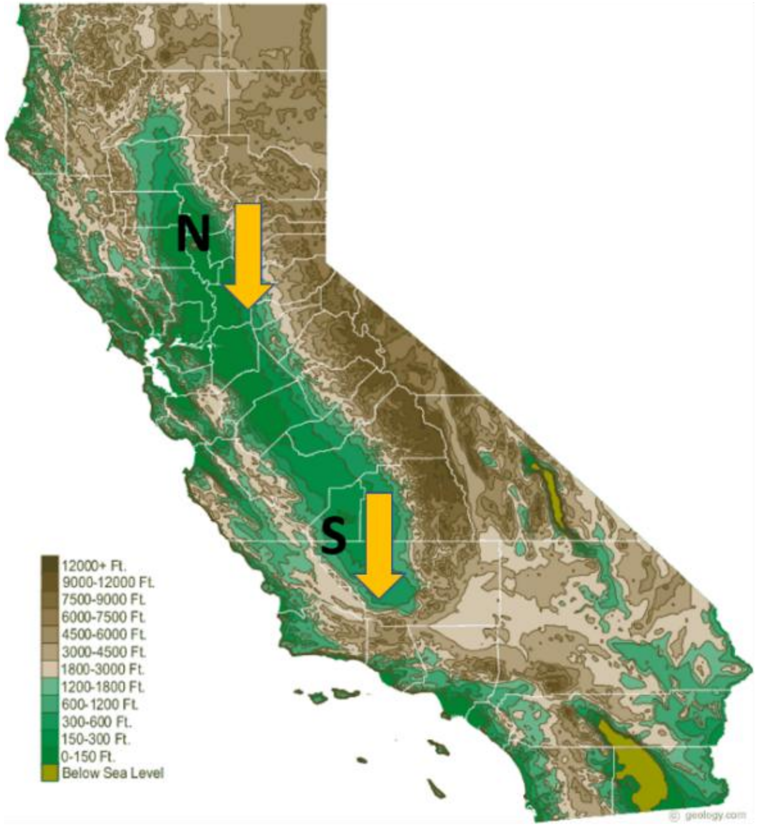
Non-structural carbohydrates as biomarkers of dormancy status



MANAGEMENT

Improve climate change mitigation strategies

Methods



Historical chill portion (CP) accumulation: 70 (S) – 80 (N)

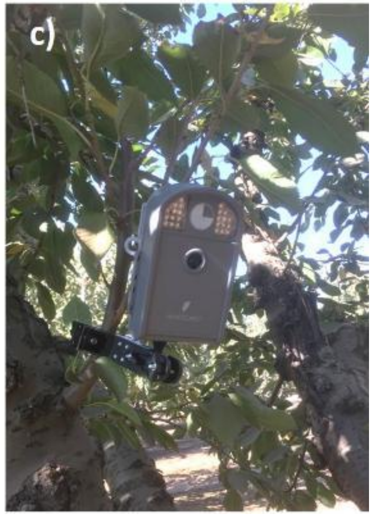
3 orchards, 3 years

Tree bark temperature

Orchard micro-climate

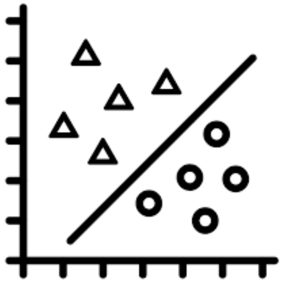
CIMIS
CALIFORNIA IRRIGATION MANAGEMENT INFORMATION SYSTEM
CALIFORNIA DEPARTMENT OF WATER RESOURCES

Macro-climate



Phenology

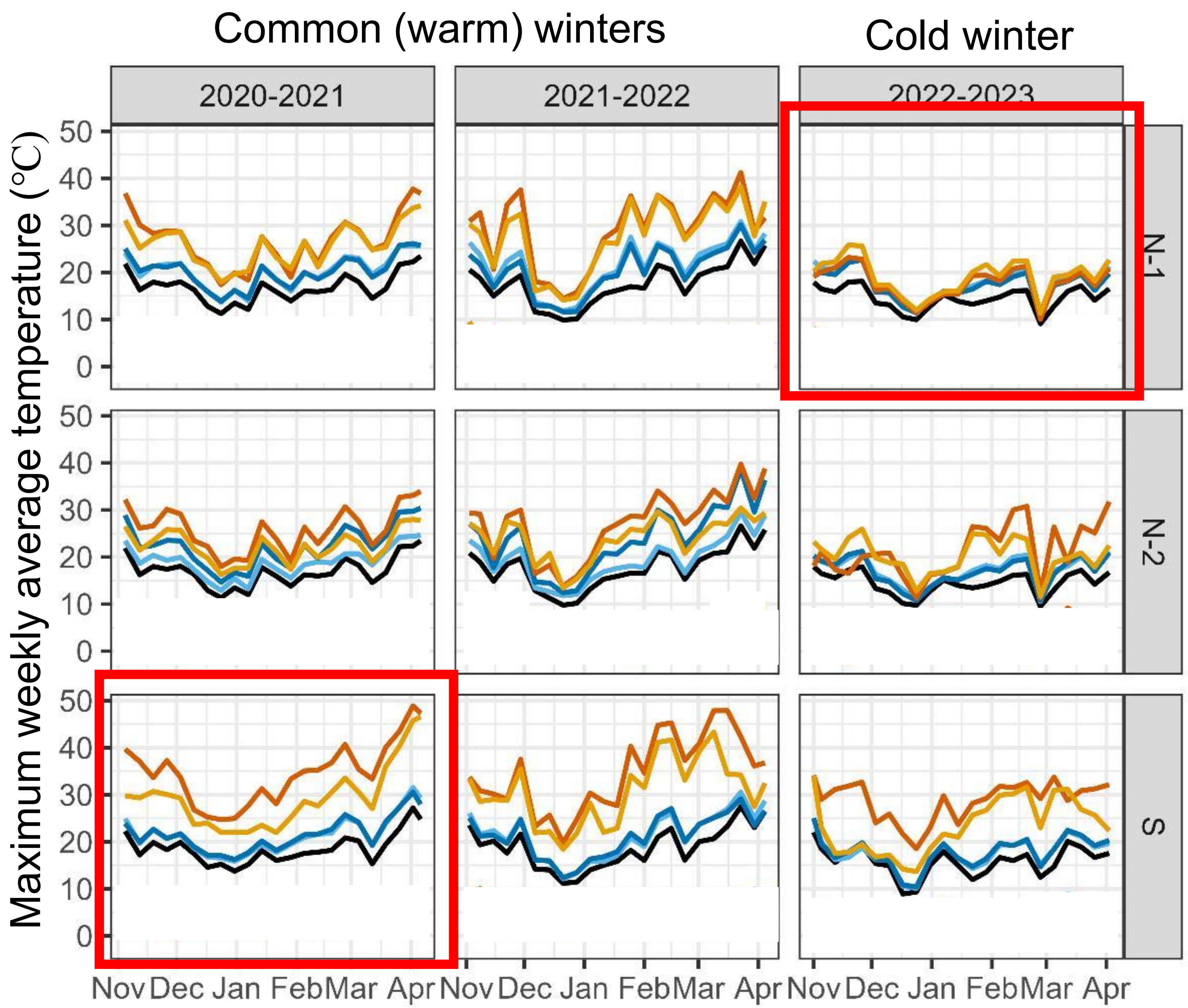
NSC sampling

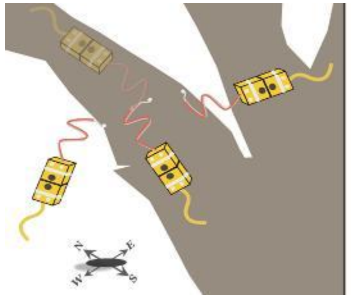


Modelling

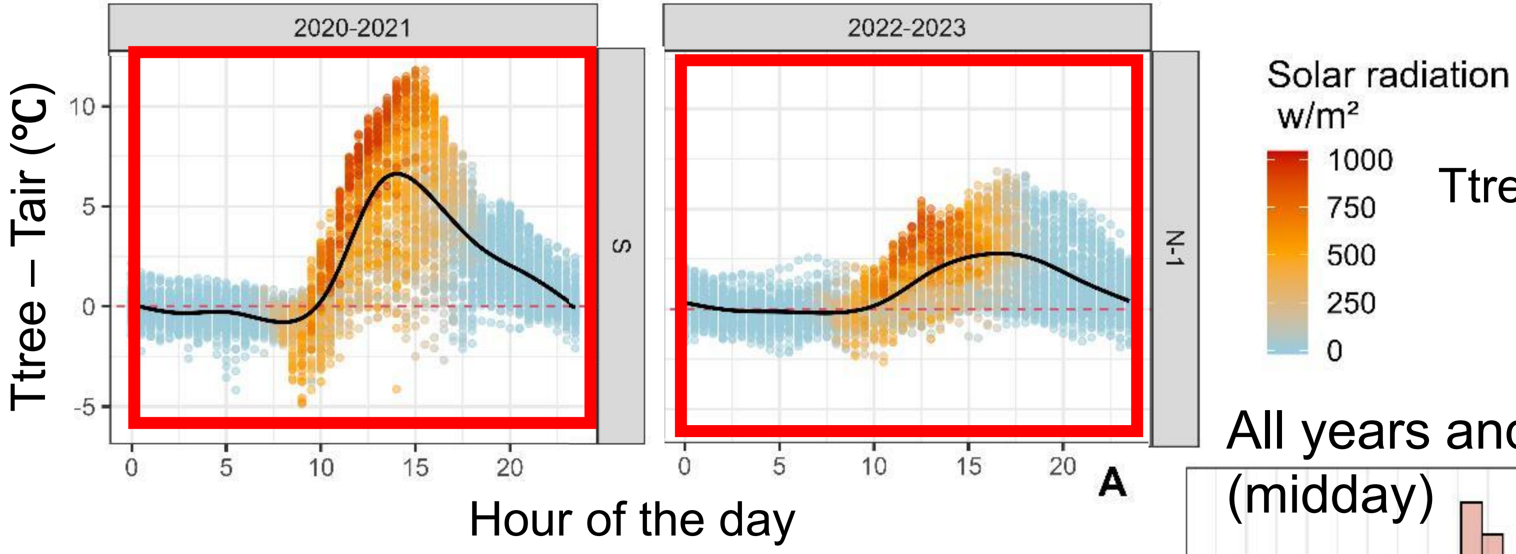
Guzmán-Delgado et al. 2025, Ag. For. Met.

Results



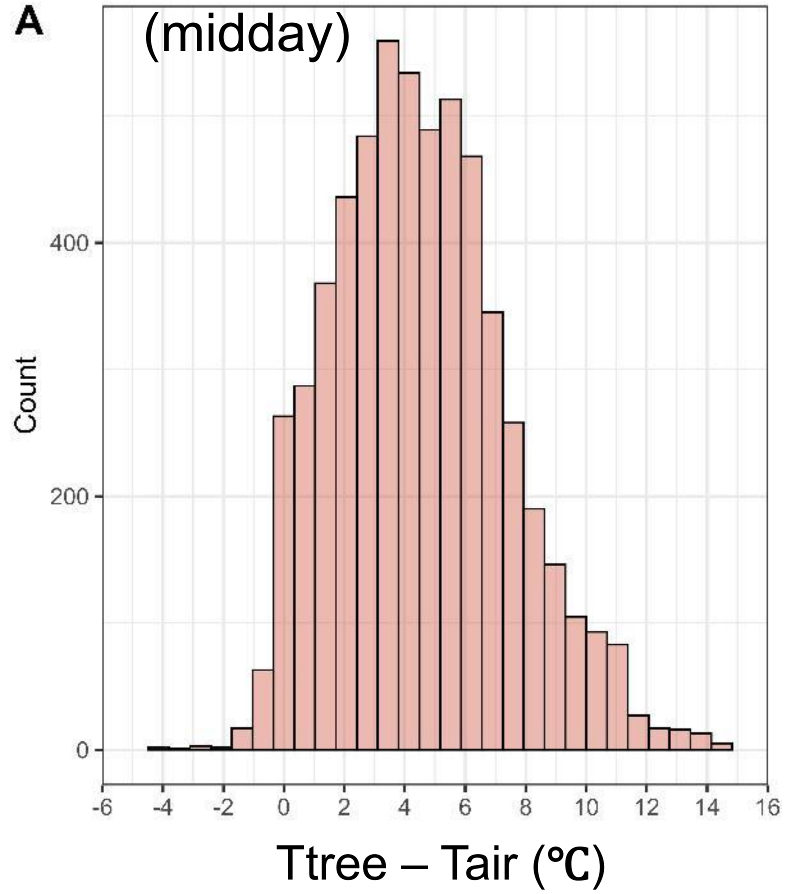


T branch



Ttree = $\overline{\text{Tbranch}}$

All years and locations (midday)

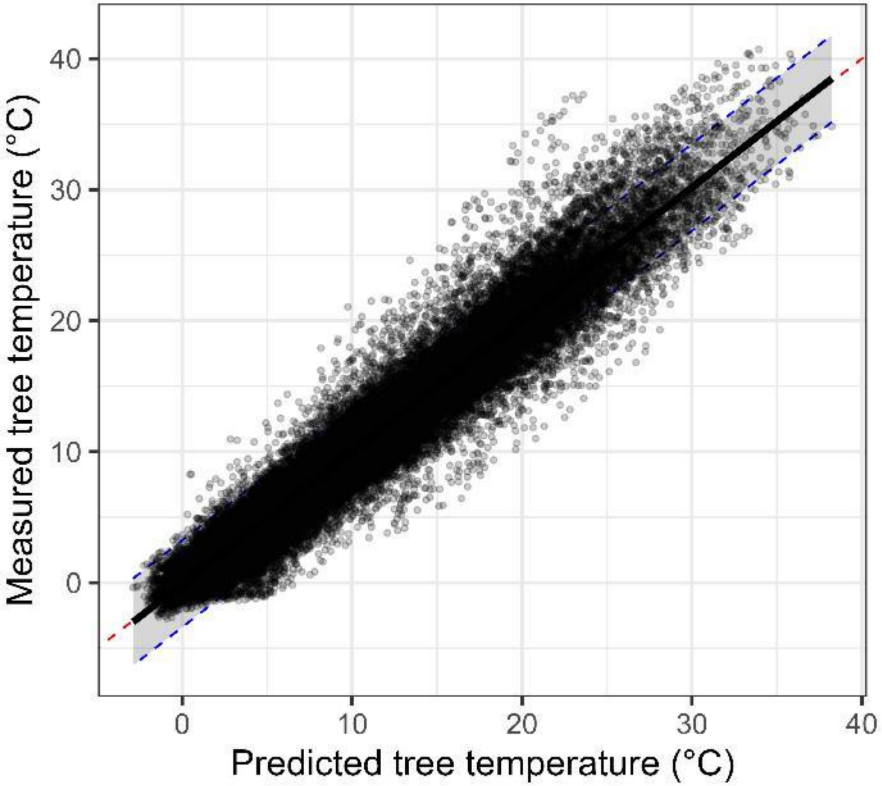


- ‘Tree temperature’ is affected by various weather variables, including solar radiation
- **‘Tree temperature’** is, on average, **3-7 ℃ higher** than ‘Air temperature’

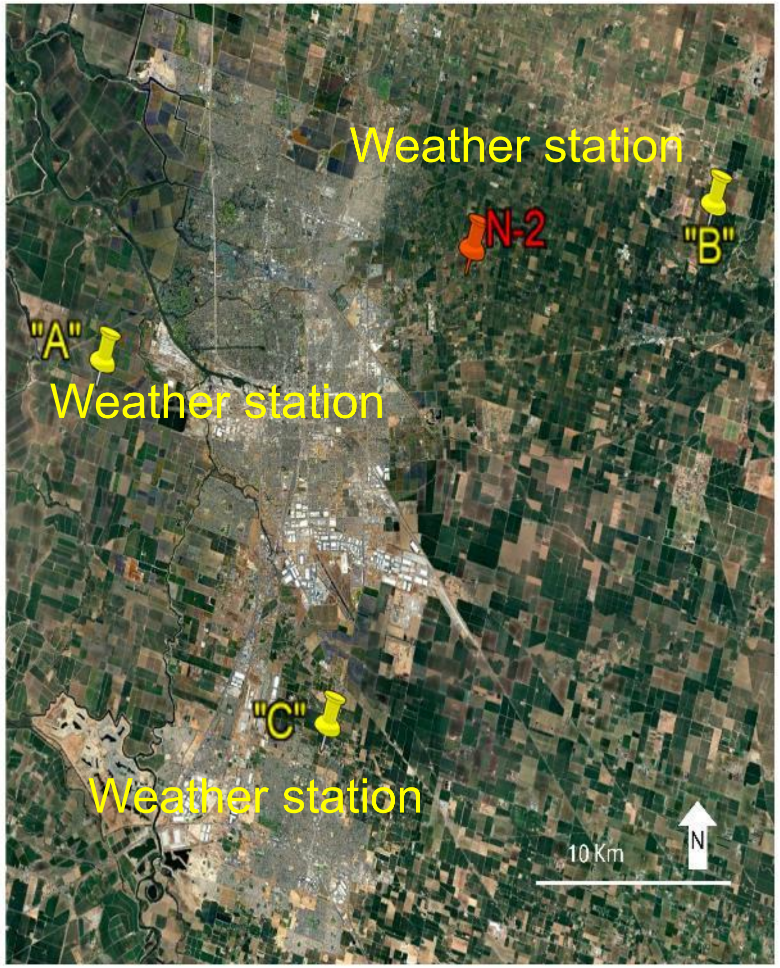
The *TreeChill* model

Cherry Chill Shiny App
https://ucanr-igis.shinyapps.io/cherrychill/

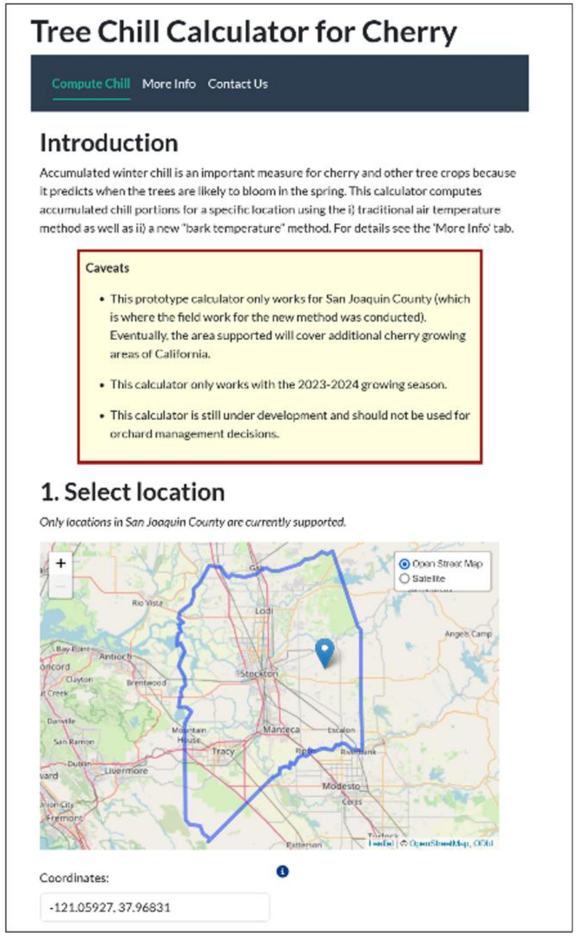
Predicts 'Tree temperature' from public weather data

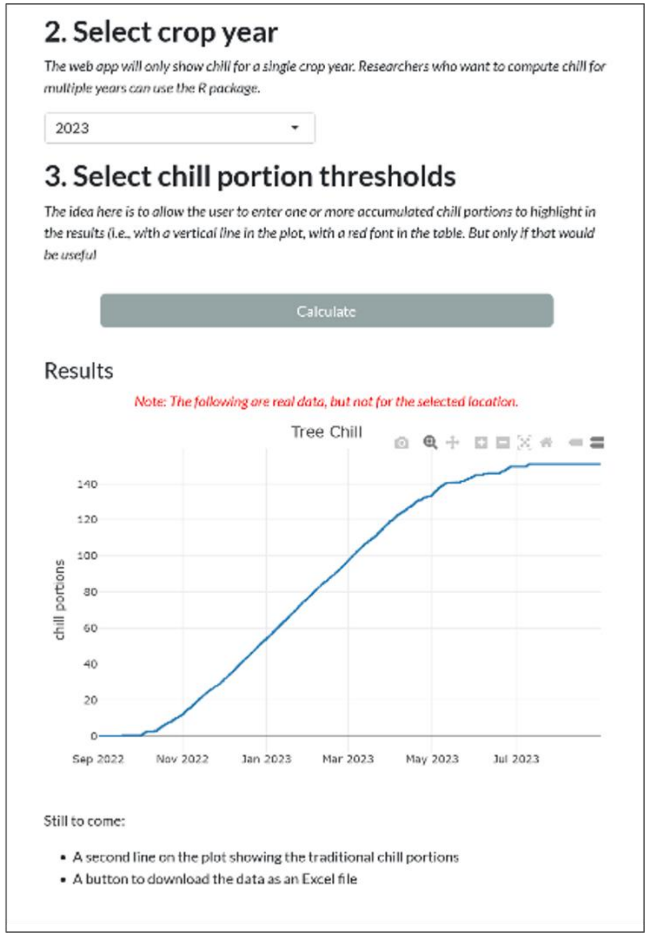


Test.data	RMSE.test	RMSE.train	R2.test	R2.train
N1	1.941	1.471	0.937	0.962
N2	1.526	1.631	0.956	0.956
S	2.406	1.416	0.917	0.961

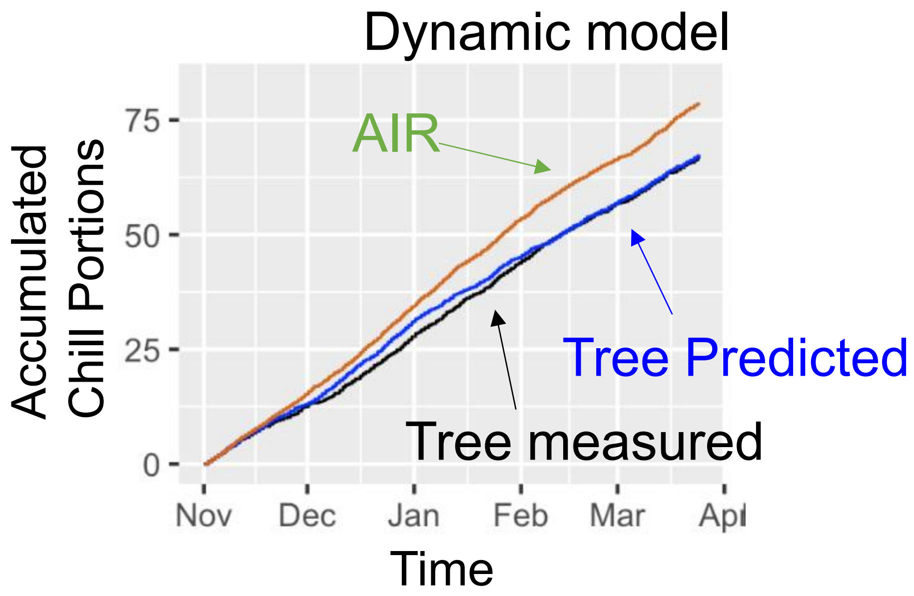


Objective 4: Developing an on line calculator for the TreeChill accumulation





Application - Chill accumulation calculations

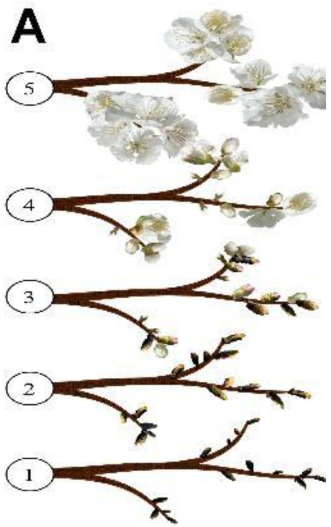


The ‘Chill_tree’ is **~10 CP lower** than the ‘Chill_Air’

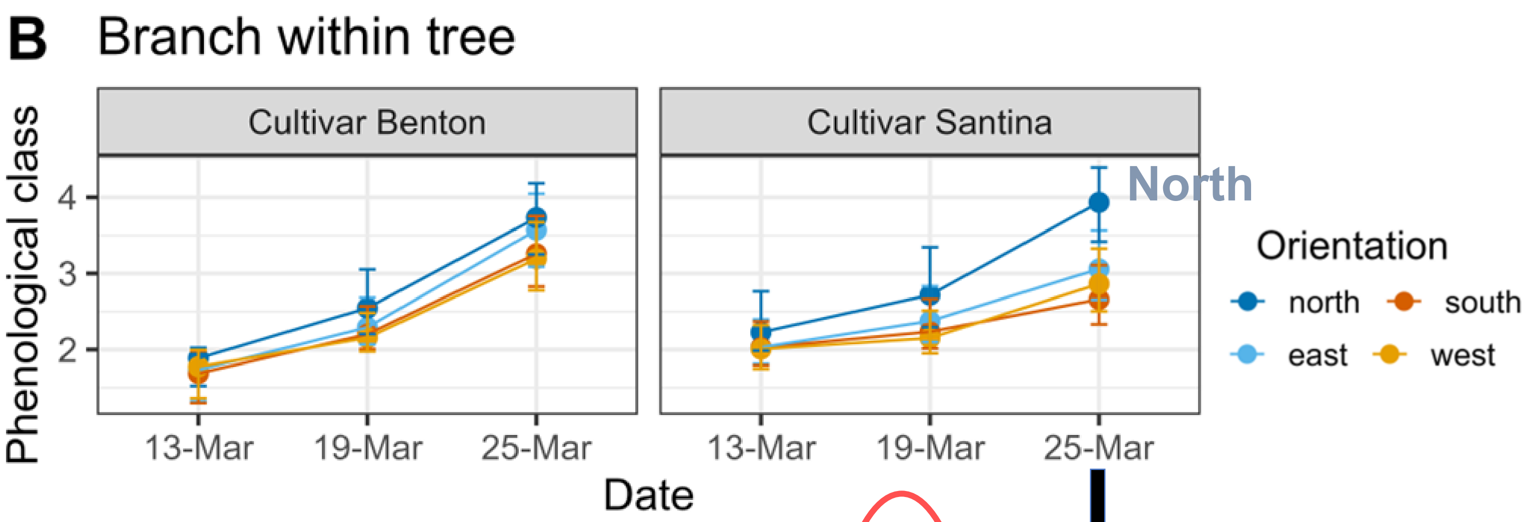
Orchard	Year	S	N	E	W	T_{tree}	pT_{tree}	T_{air}
N-1	2020–2021	58.9	67.5	65.0	59.5	62.6	62.9	71.4
	2021–2022	58.2	64.8	63.5	57.4	59.0	60.7	73.1
	2022–2023	69.2	70.9	68.4	67.2	68.7	71.5	78.3

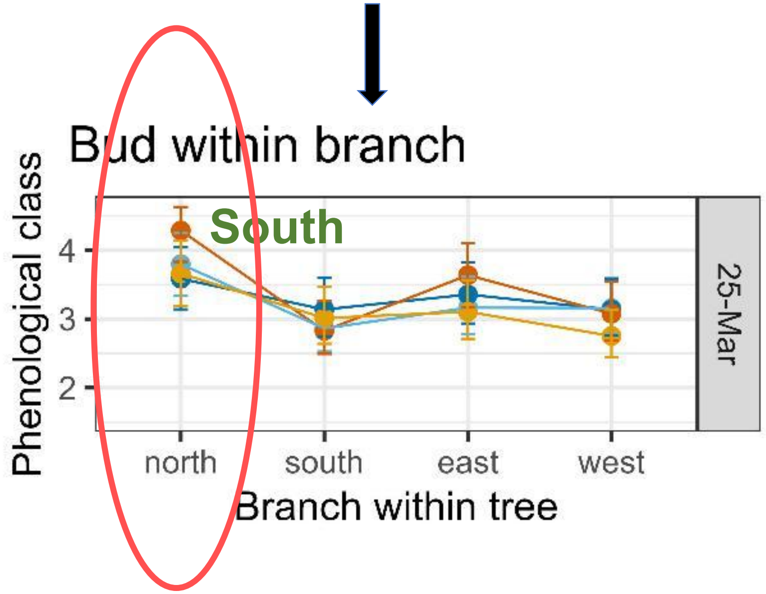
‘Tree chill’ calculator: https://ucanr-igis.shinyapps.io/cherrychill/

Phenology



Phenological class



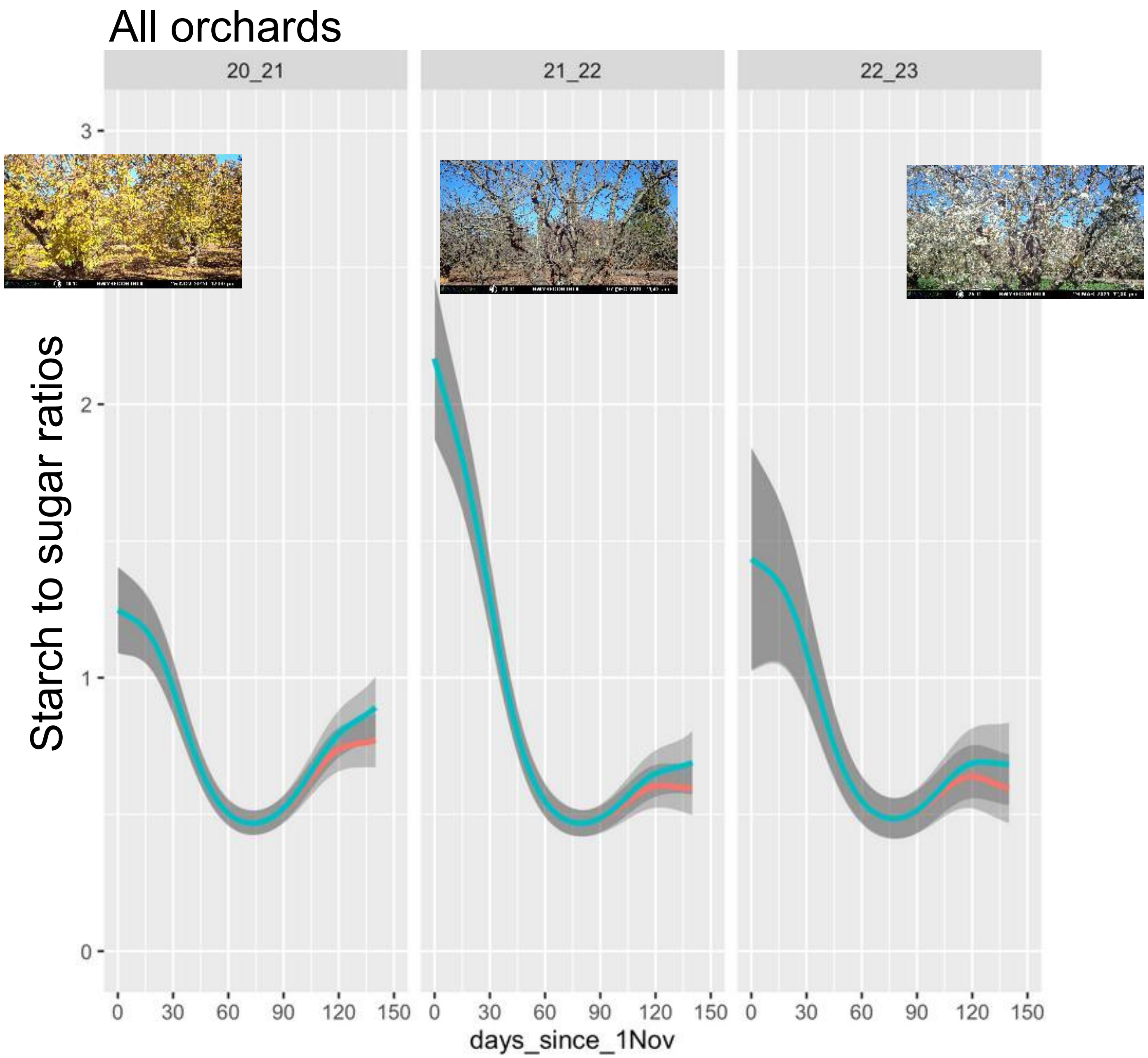


Buds located in the south of the north branches bloom first:

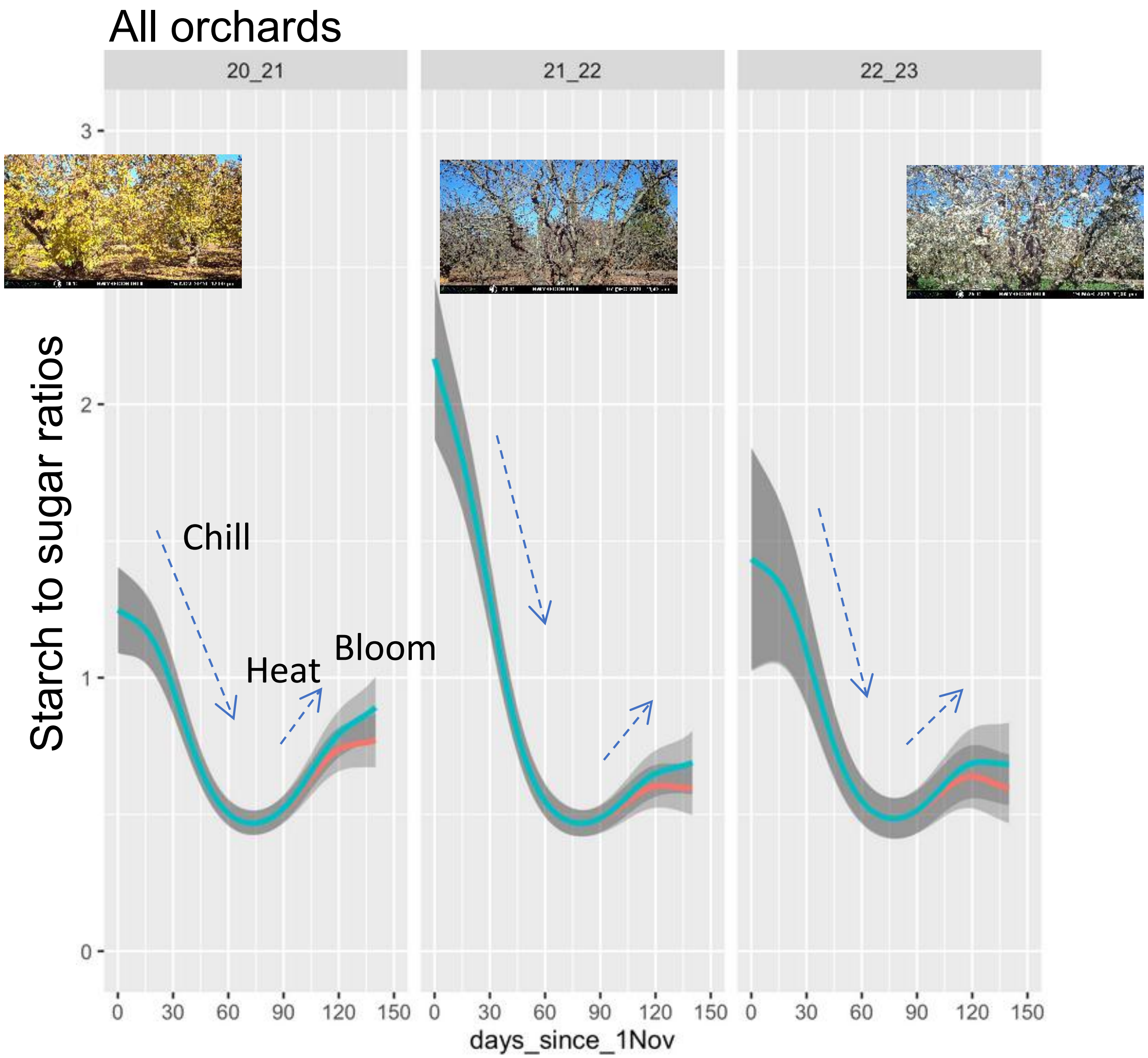
1st Colder branch orientations – chill accumulation

2nd Warmer bud orientations – heat accumulation

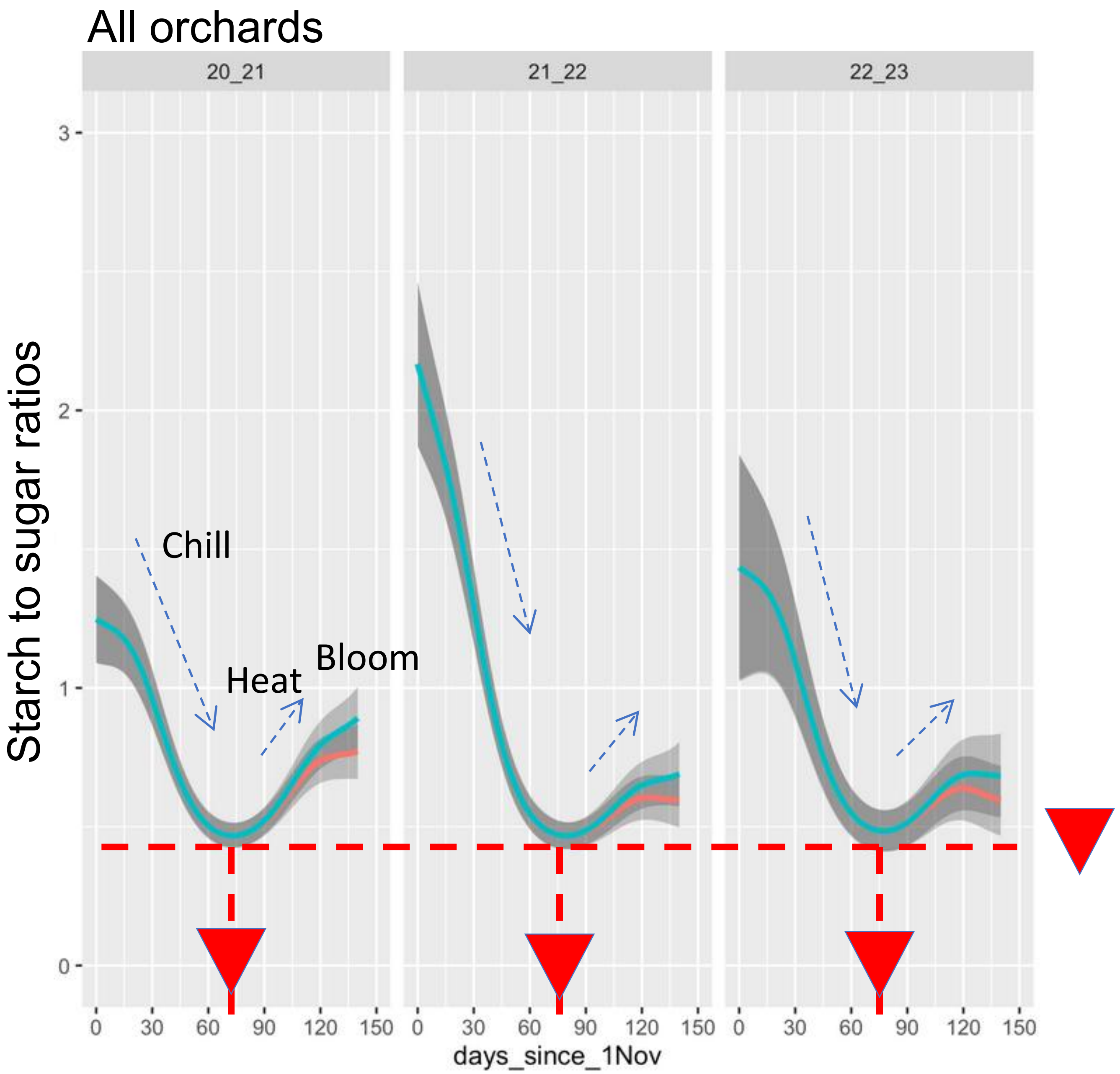
Non-structural carbohydrate dynamics



Non-structural carbohydrate dynamics



Non-structural carbohydrate dynamics



CP_Air = 45-50
Recommended spray application (empirical)

Applications and outcomes

- Better understanding of the mechanisms of chill
- Improve management: Dormancy breaking agent (DBA) timing, pest modeling, cultivar selection, orchard design, etc.

Next steps

- Timing DBA application based on '*TreeChill*' and NSC
- Apply an energy balance approach to the '*TreeChill'* model to adapt it to different locations
- Integrate whole-tree temperature dynamics

Pistachio Flowers

- **100-200 flowers**

  <4% set, resulting in an average of 14 nuts/cluster

  With 5-30% blanks

  - parthenocarpy
- **Apically dominant**
  - **Most nuts are at the terminus (8% of total flowers)**
- **Fruit is a drupe**
- **Capable of parthenocarpy**

Pistachio Nut Growth:

Spring → Summer





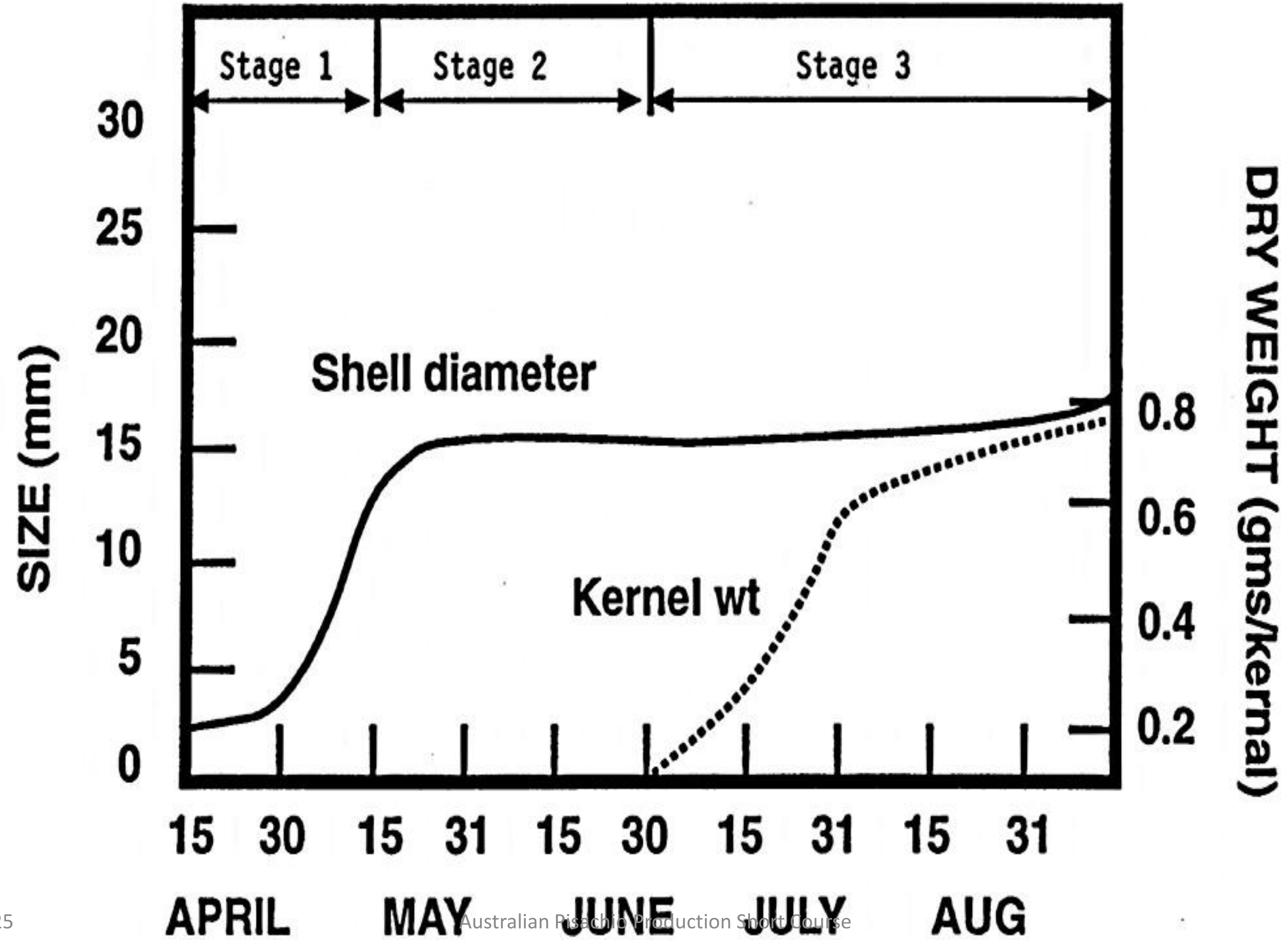
Stage I: Shell growth; irrigation

Stage II: Shell hardening and thickening; small bugs

Stage III: Kernel growth: irrigation, NOW and harvest

Manage pistachio production by:

- Calendar date
- Monitoring temperatures
- Examining nuts directly
  - regulated deficit irrigation
  - pest management
  - harvest



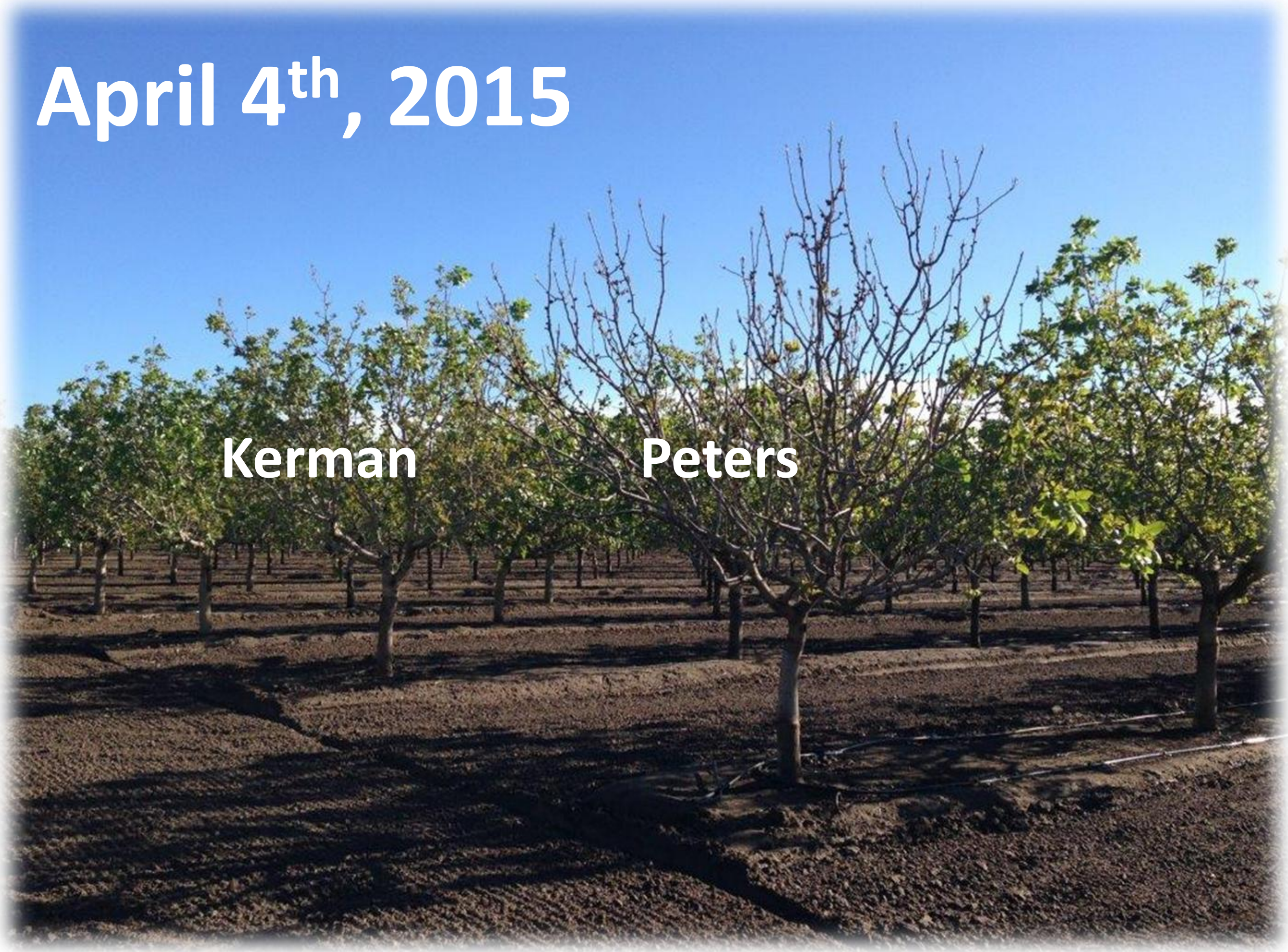
Stage 1
Stage 2
Stage 3
SIZE (mm)
30
25
20
15
10
5
0
Shell diameter
Kernel wt
DRY WEIGHT (gms/kernal)
0.8
0.6
0.4
0.2
15
30
15
31
15
30
15
31
15
31
APRIL
MAY
JUNE
JULY
AUG

Worked well until:

- **New cultivars were released…**

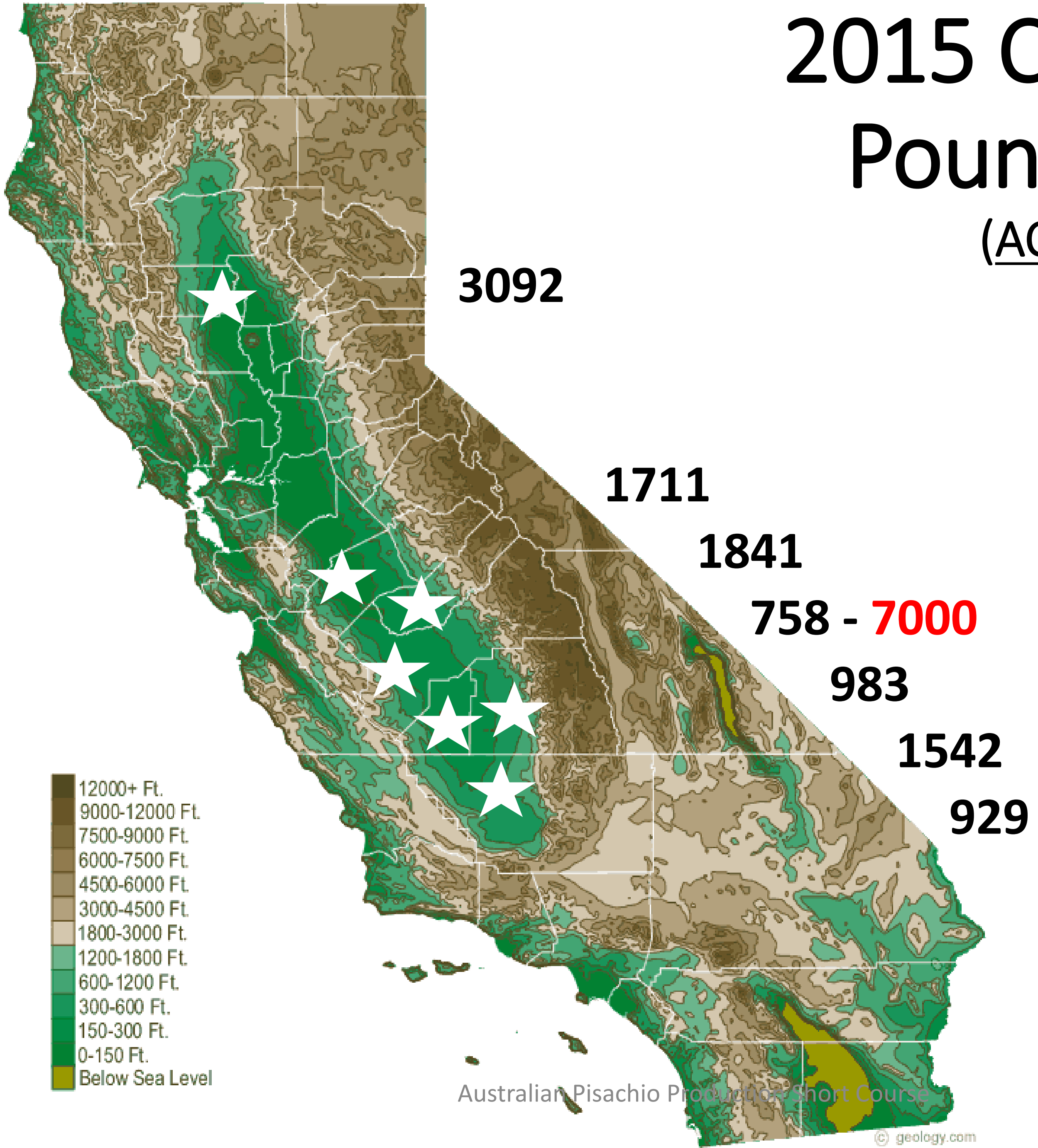
Worked well until:

- **Climate started changing:**



2015 County Yield Pounds per Acre

(ACPistachios.org 2016)

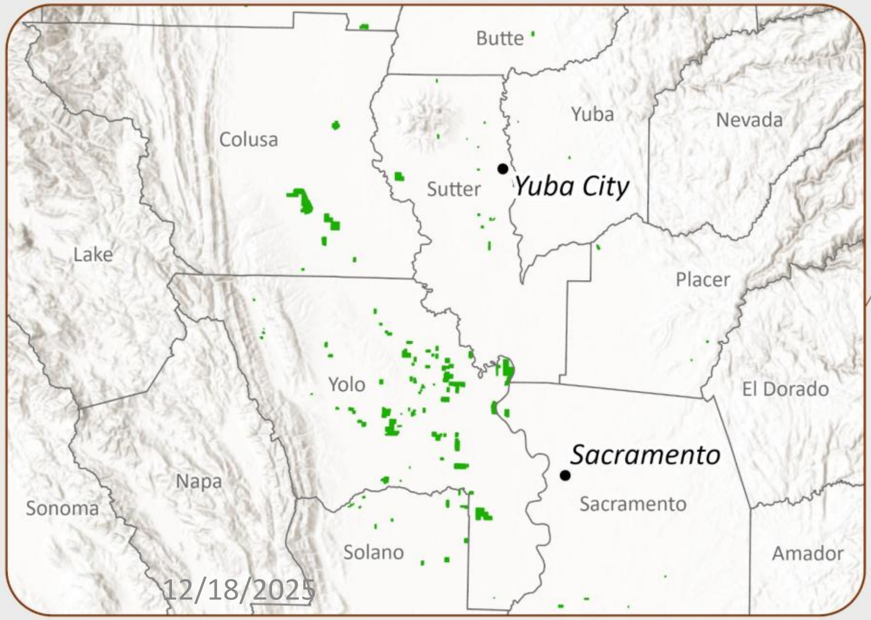


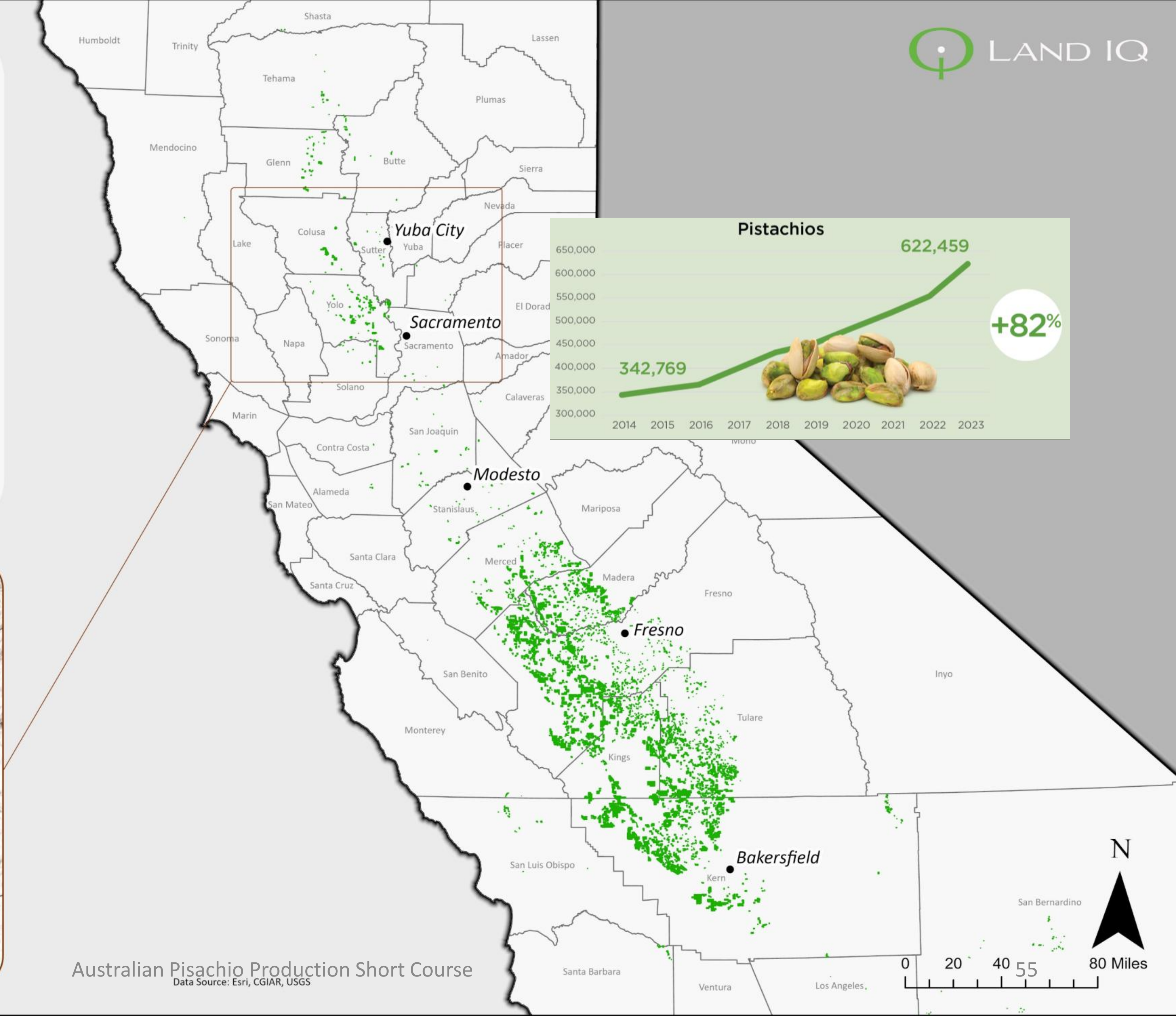
2023 Pistachios

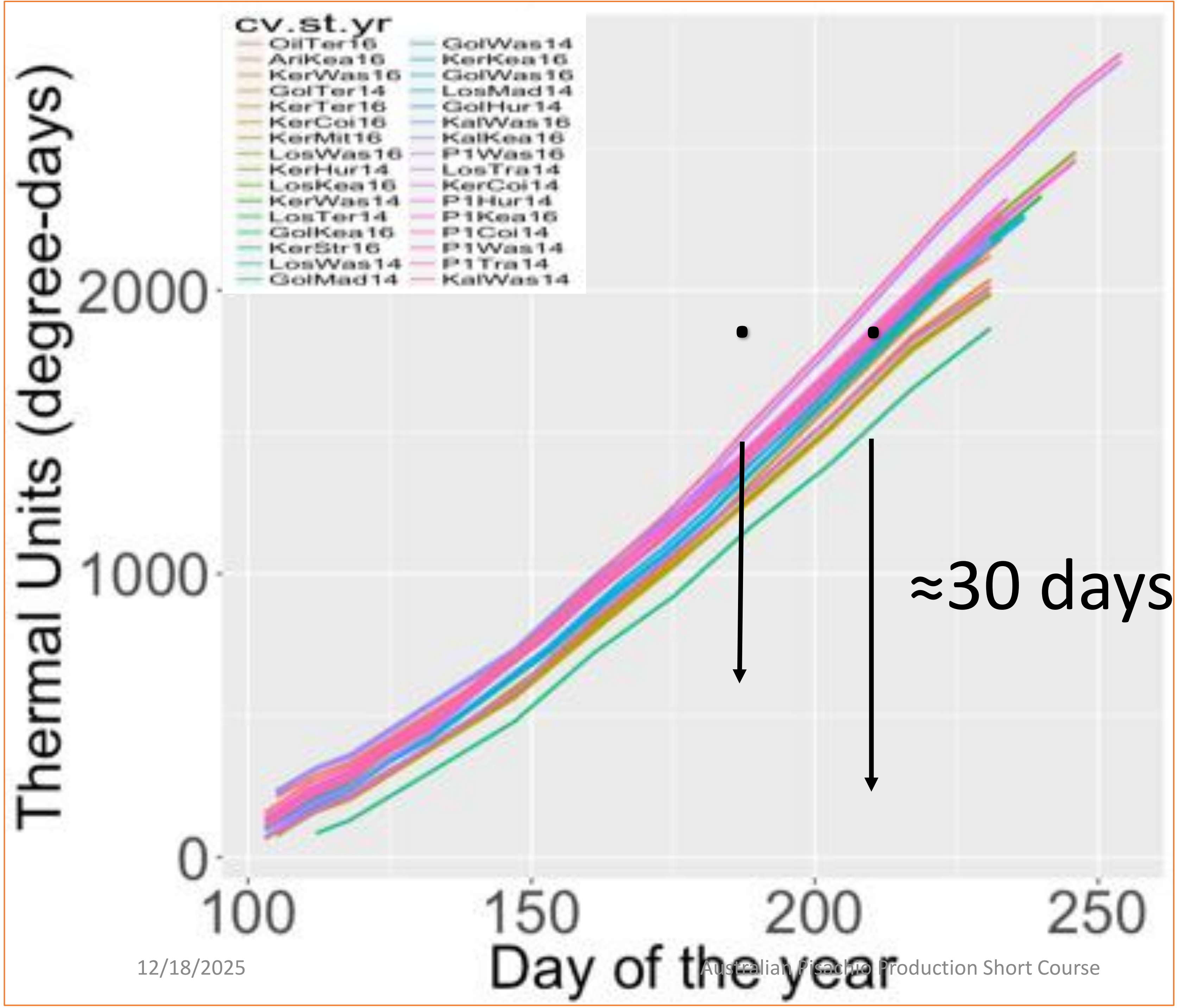
Total Acreage: 622,459

Acreage of Top 5 Pistachio-Growing Counties:

1. Fresno: 169,162
2. Kern: 167,494
3. Tulare: 86,643
4. Kings: 63,716
5. Madera: 58,501







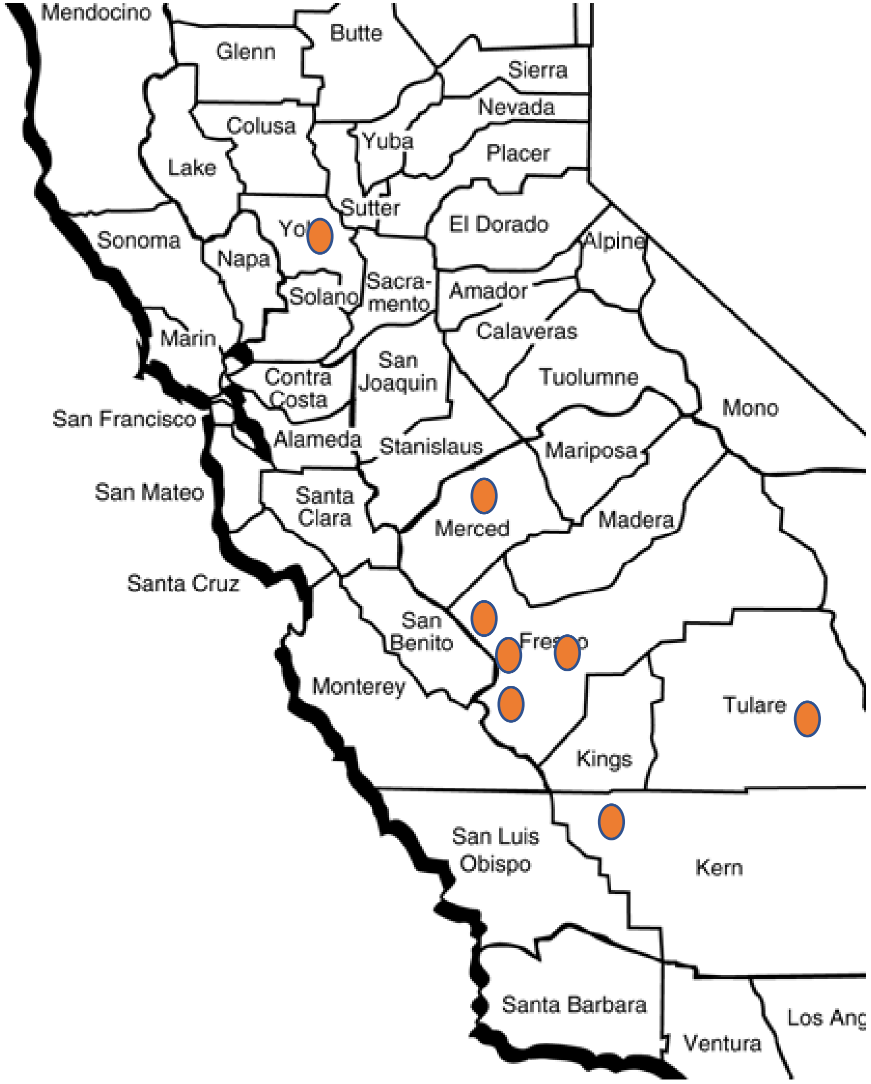
Planting at different sites:
- different microclimates

Temperature drives tree and nut growth and ripening:

- **Plants have genetically determined heat unit accumulation requirements for growth stages:**
  - **above a minimum temperature: 45ºF (7.5ºC)**
  - **Growing Degree Days: GDD**

Sampling Locations and Cultivars:

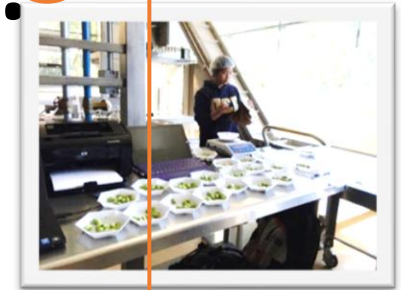
- **4 years: 2013, 2014, 2016, 2017**
- **8 locations:**
  300 miles from south to north
- **6 cultivars:**
  Kerman, Lost Hills,
  Golden Hills, Kaleghouchi,
  Pete 1 and Aria
- **7-day sampling intervals**



GOAL: demonstrate growth and ripening is a function of heat units not time (date)

Lab measurements…

1



Sorted

2 Photographed

3 Measured

4

Punctured
(shell firmness)

5

Separated
(kernel)

6 Weighed

Growing Degree Day Requirements:

	Kerman	Golden Hills	Lost Hills
Stage I	756	705	751
Stage II	2583	2830	3157
Stage III	Starts at 1000, ends at 2111	Starts at 931, ends at 1904	Starts at 982, ends at 2021

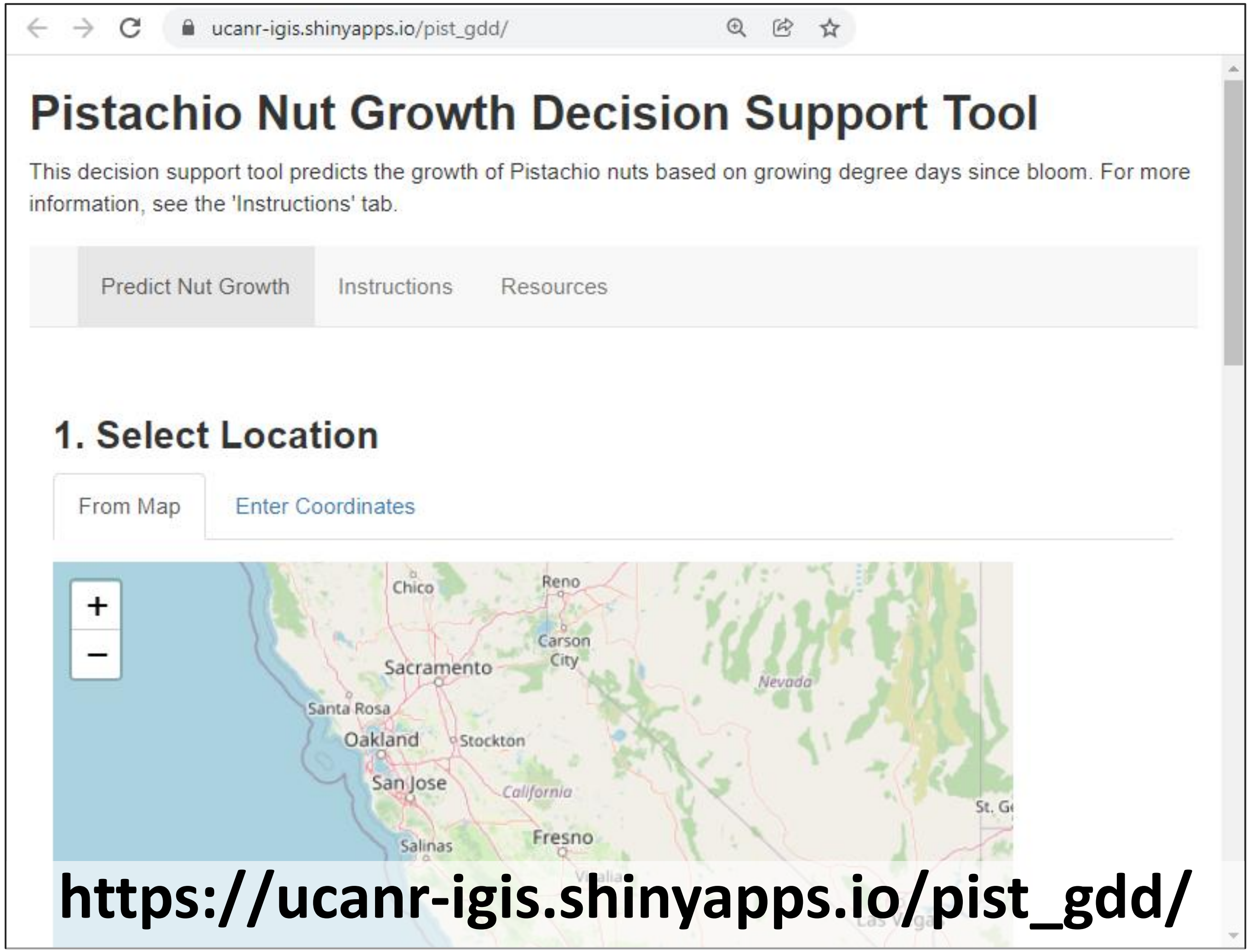
Decision Support Tool:

You provide the:

- **location**
- **cultivar**
- **bloom date**

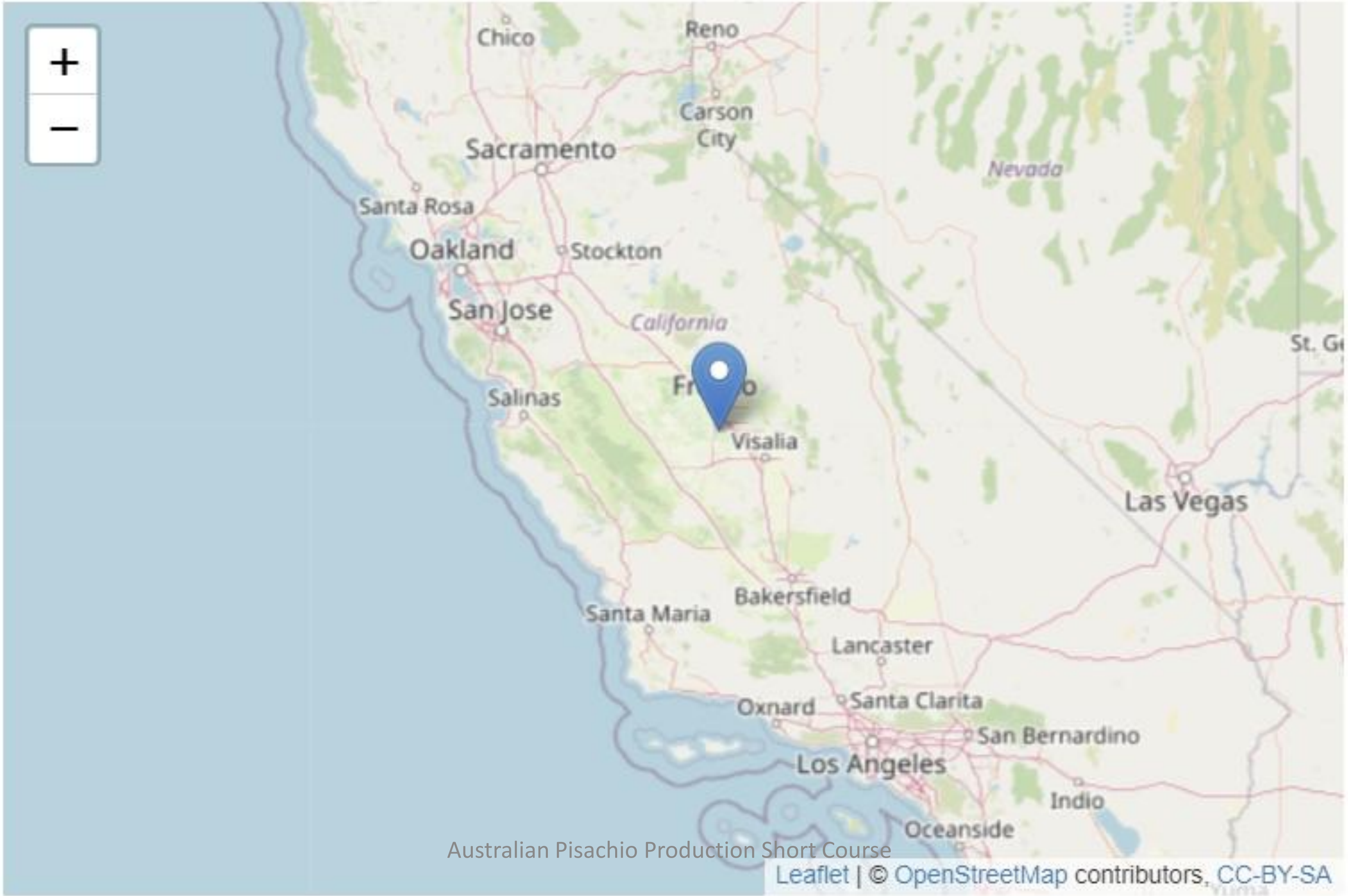
The website will:

- **lookup weather data**
- **compute the GDD**
- **estimate nut development dates**



1. Select Location

From Map | Enter Coordinates



2. Pistachio options

Cultivar:

Kerman ▼

Date range:

2021-03-15 to 2021-10-31

Percent of maximum to flag:

90

3. Weather data

Start date to yesterday:

World Weather Online ▾

Next 10 days:

World Weather Online ▾

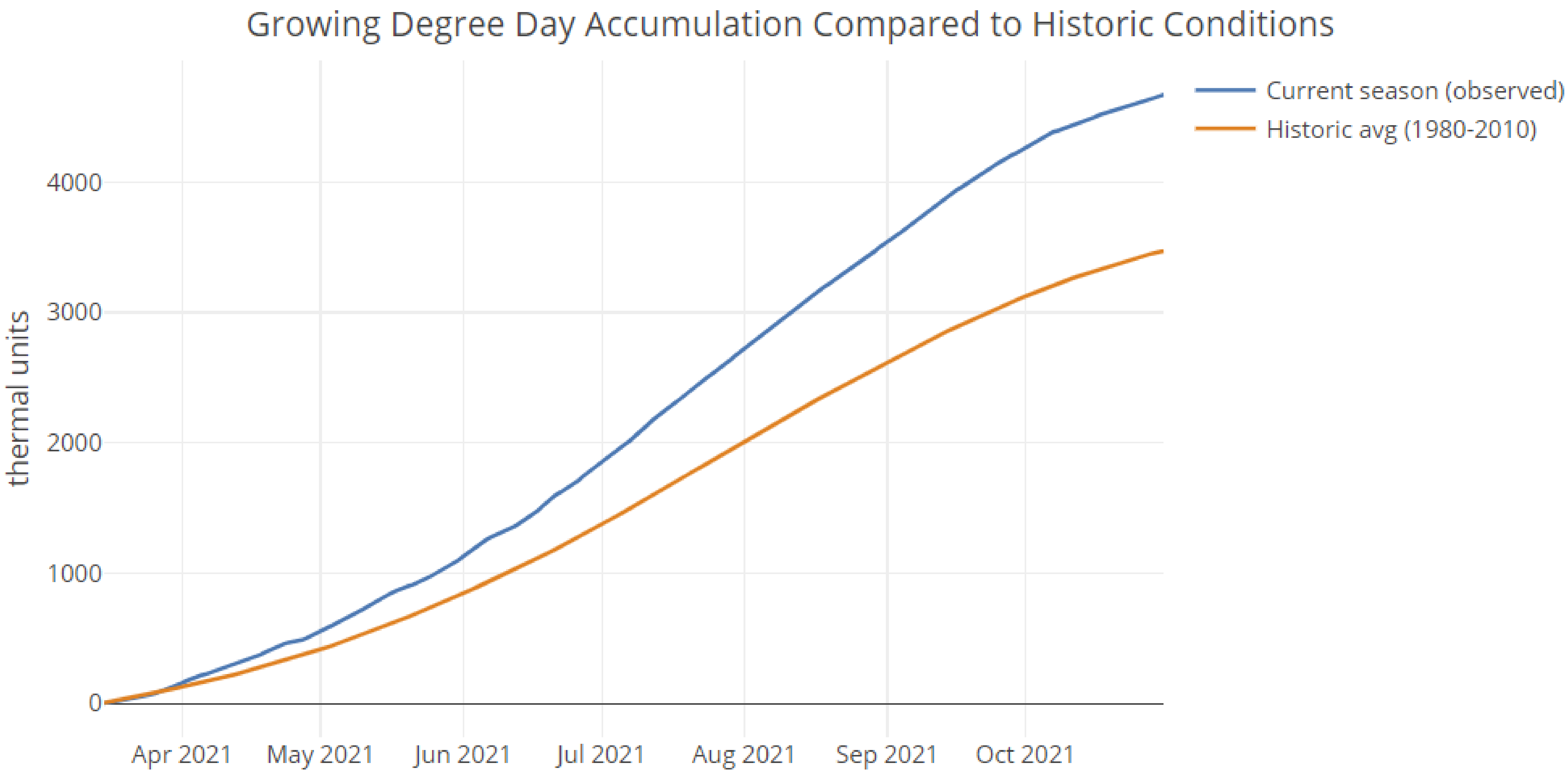
Historical reference:

CalAdapt (Livneh) ▾

Historical date range

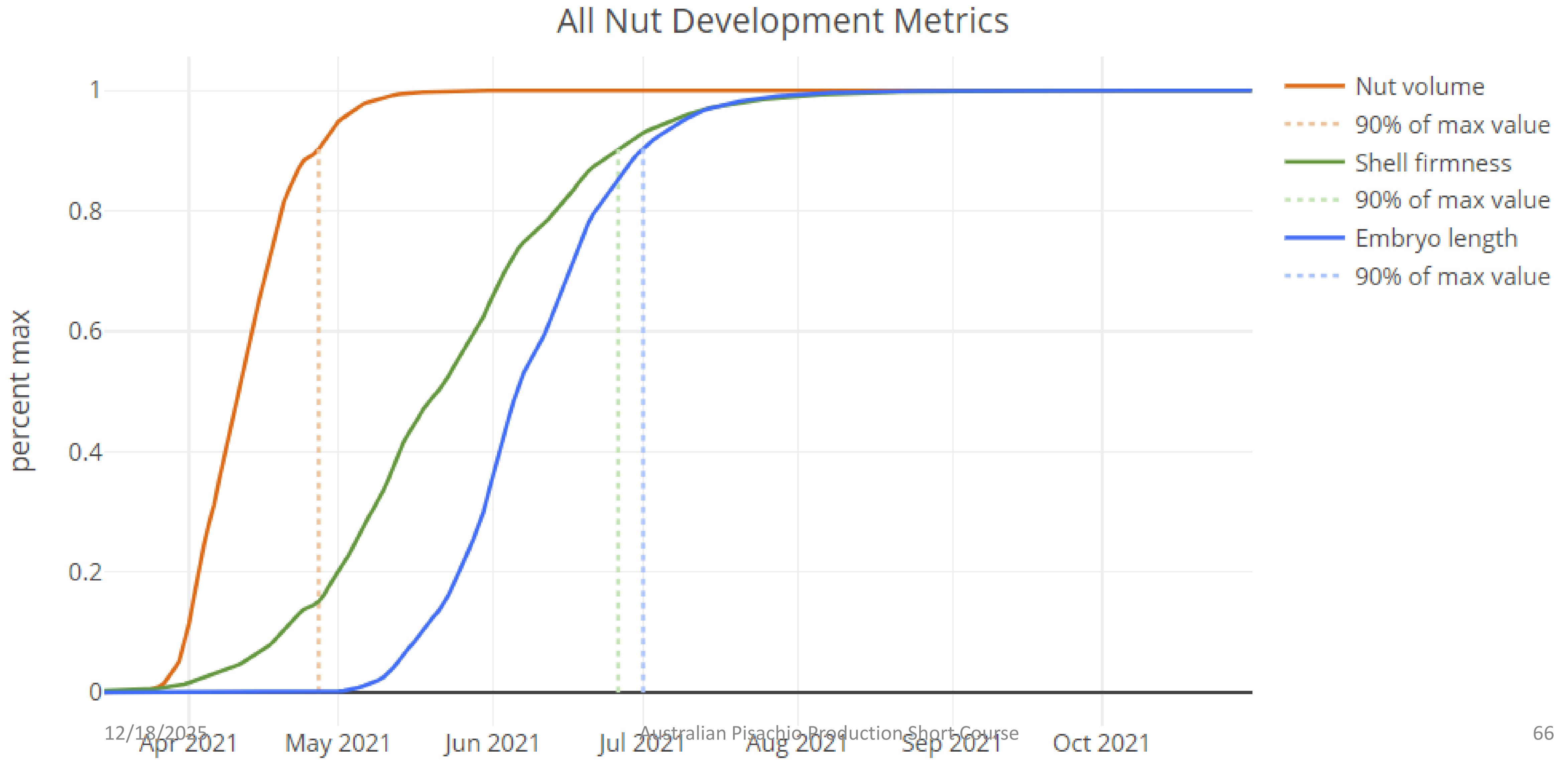
1950 — 1980 to 2010

1950 1956 1962 1968 1974 1980 1986 1992 1998 2004 2010


Growing Degree Day Accumulation Compared to Historic Conditions
Current season (observed)
Historic avg (1980-2010)
thermal units
4000
3000
2000
1000
0
Apr 2021
May 2021
Jun 2021
Jul 2021
Aug 2021
Sep 2021
Oct 2021

Results

GDD (2021) | GDD (historical) | Nut Development Metrics (all) | Volume | Firmness | Embryo Length



Purpose:

- **This website is a decision support tool: ground truth**

HORTSCIENCE 56(7):769–779. 2021. https://doi.org/10.21273/HORTSCI15722-21

Nonlinear Model Selection for Fruit and Kernel Development as a Function of Heat in Pistachio

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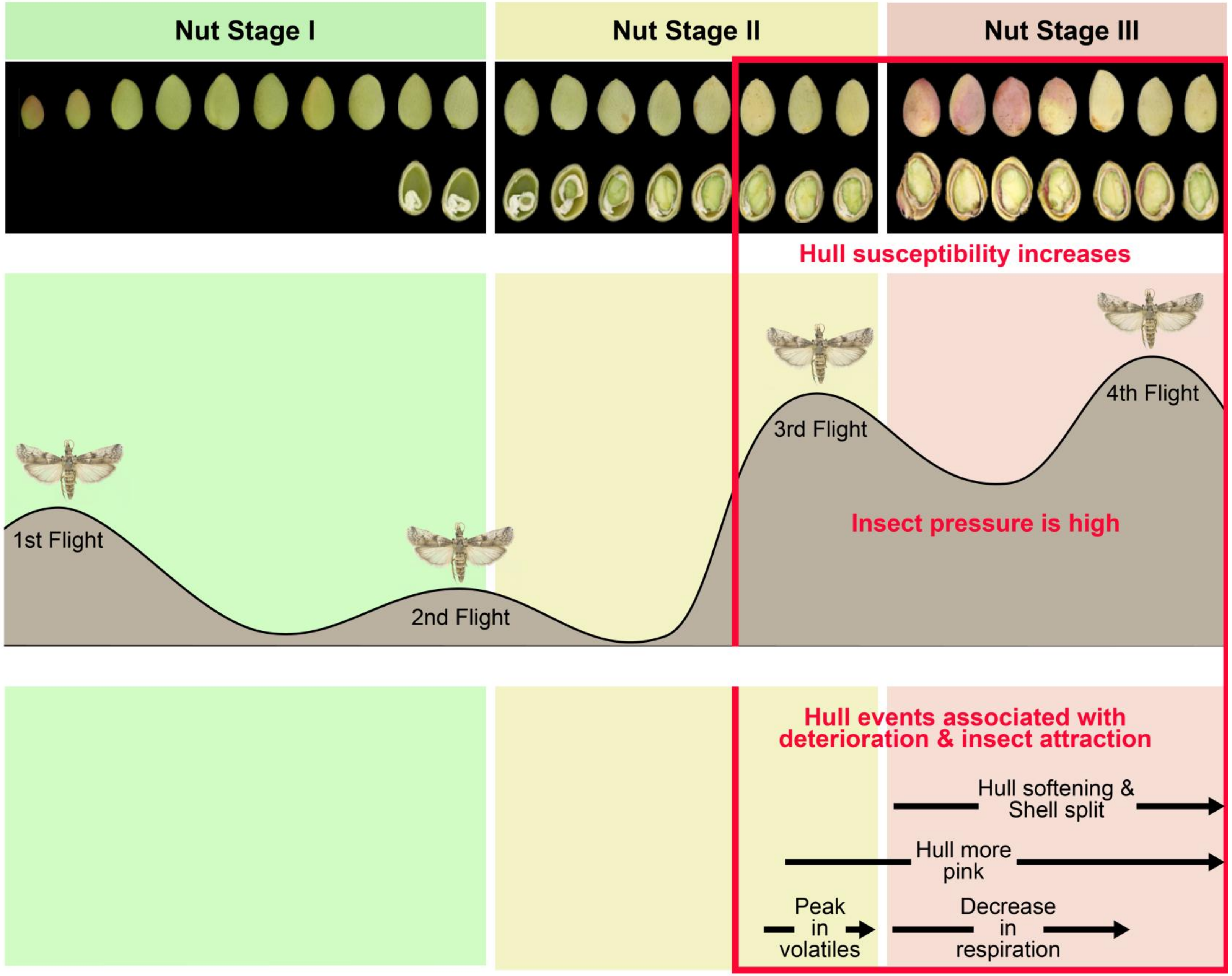
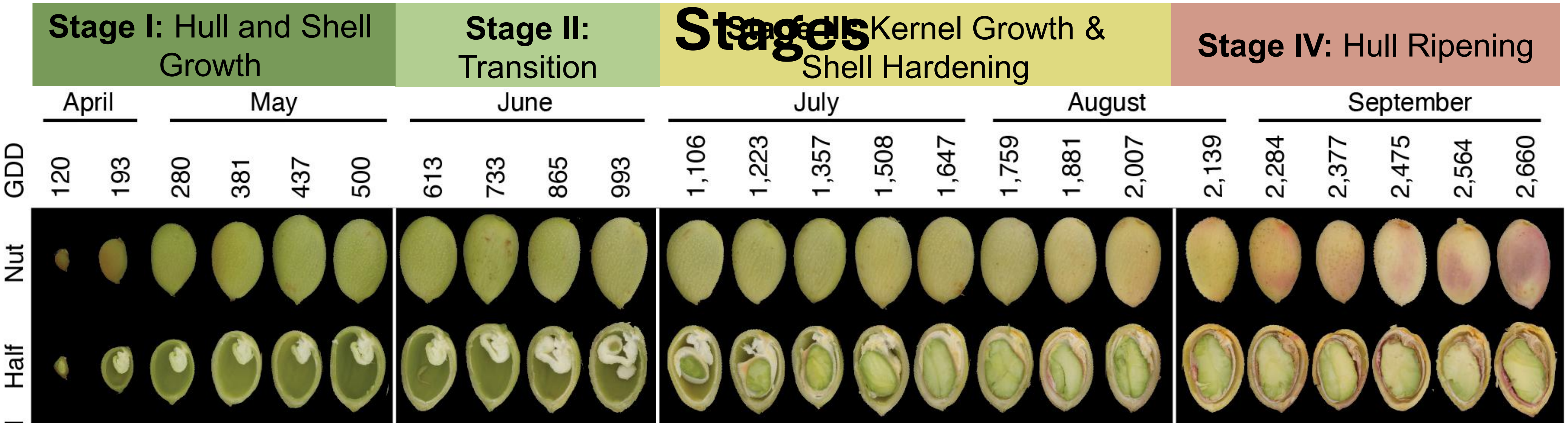


Coordinate nut development as a function of GDD:

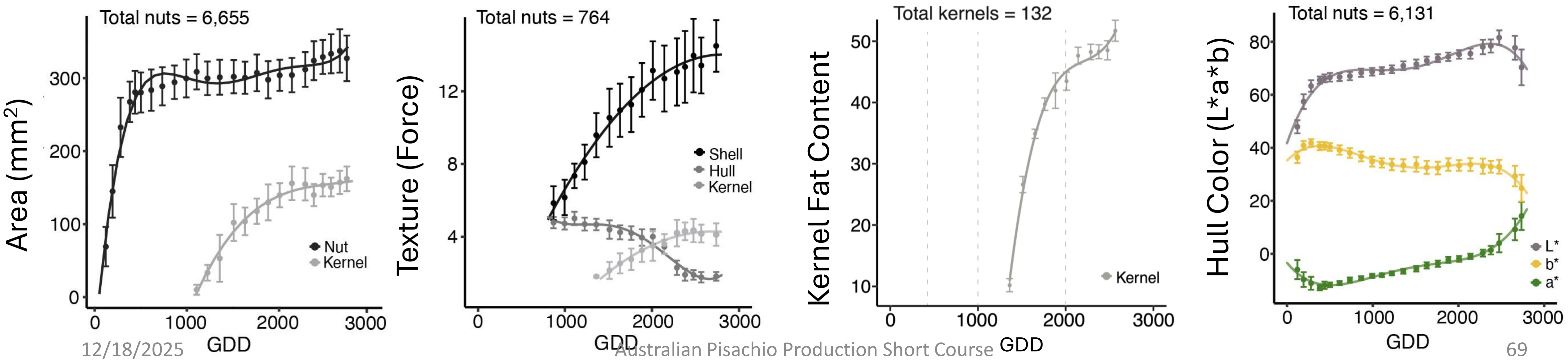
- NOW generations
- hull susceptibility

Slide: Courtesy of B. Blanco-Ulate and Houston Wilson

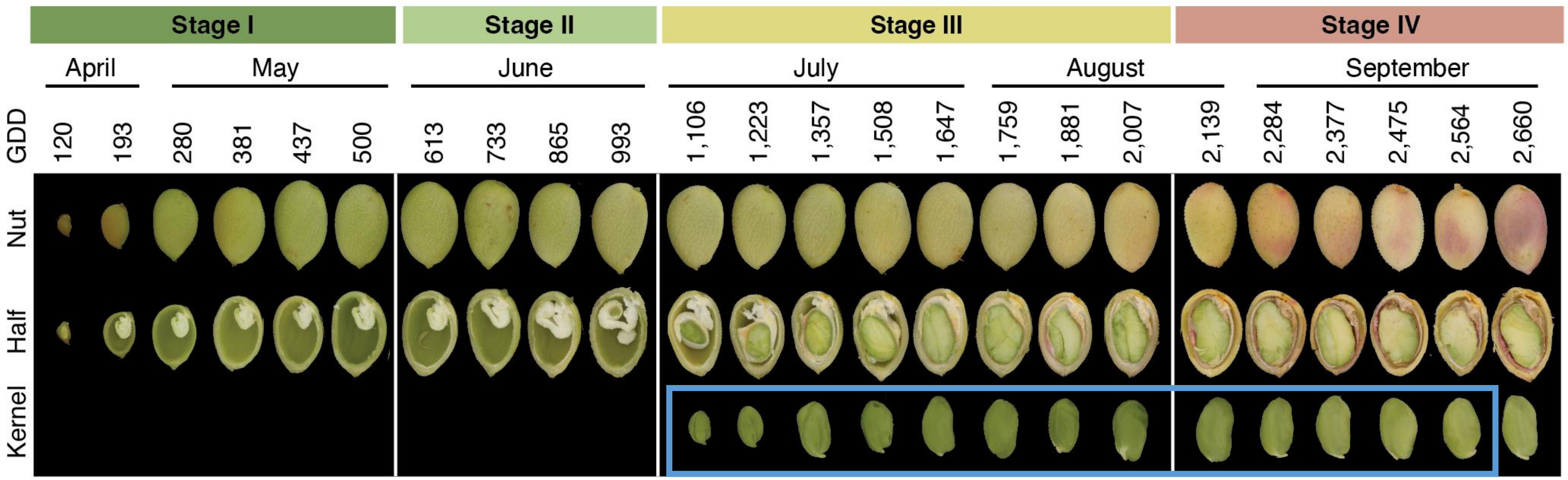
Blanco-Ulate and Marino Redefined Pistachio Development Stages

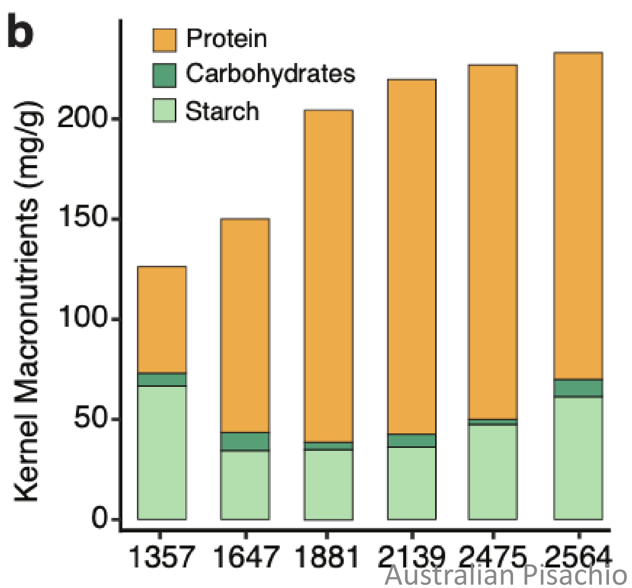


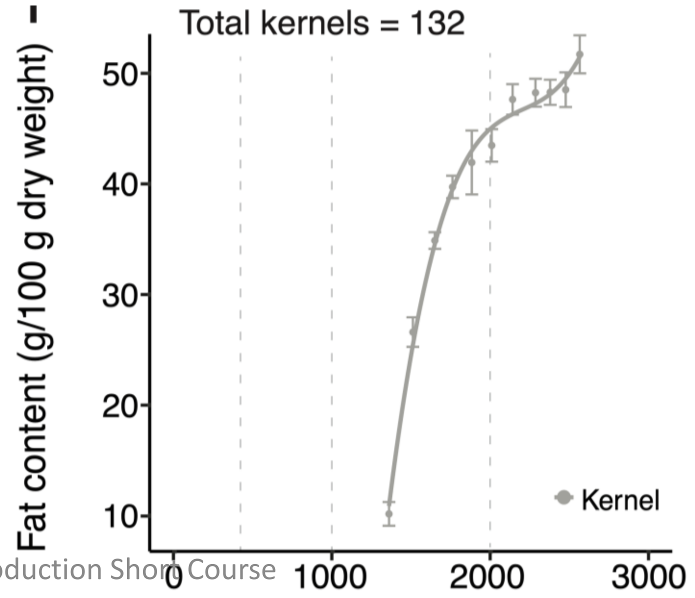
RNA Seq Study of 15 weeks x 3 tissues



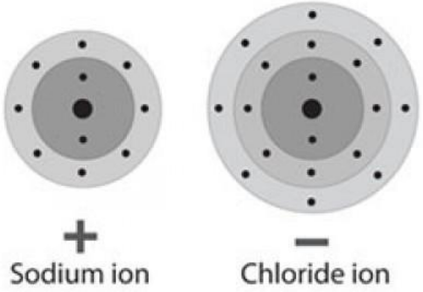
Thermal Time

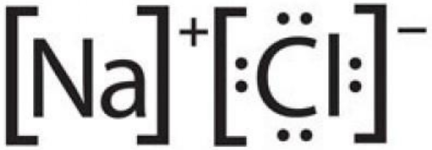

Stage I
Stage II
Stage III
Stage IV
April
May
June
July
August
September
GDD
120
193
280
381
437
500
613
733
865
993
1,106
1,223
1,357
1,508
1,647
1,759
1,881
2,007
2,139
2,284
2,377
2,475
2,564
2,660
Nut
Half
Kernel


b
Protein
Carbohydrates
Starch
Kernel Macronutrients (mg/g)
0
50
100
150
200
1357
1647
1881
2139
2475
2564


Total kernels = 132
Fat content (g/100 g dry weight)
10
20
30
40
50
Kernel
0
1000
2000
3000

Water and Soil Quality: wide range soils





Cations: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}

Anions: SO_4^{2-}, Cl^{-}, HCO_3^{-}, CO_3^{2-}, NO_3^{-}

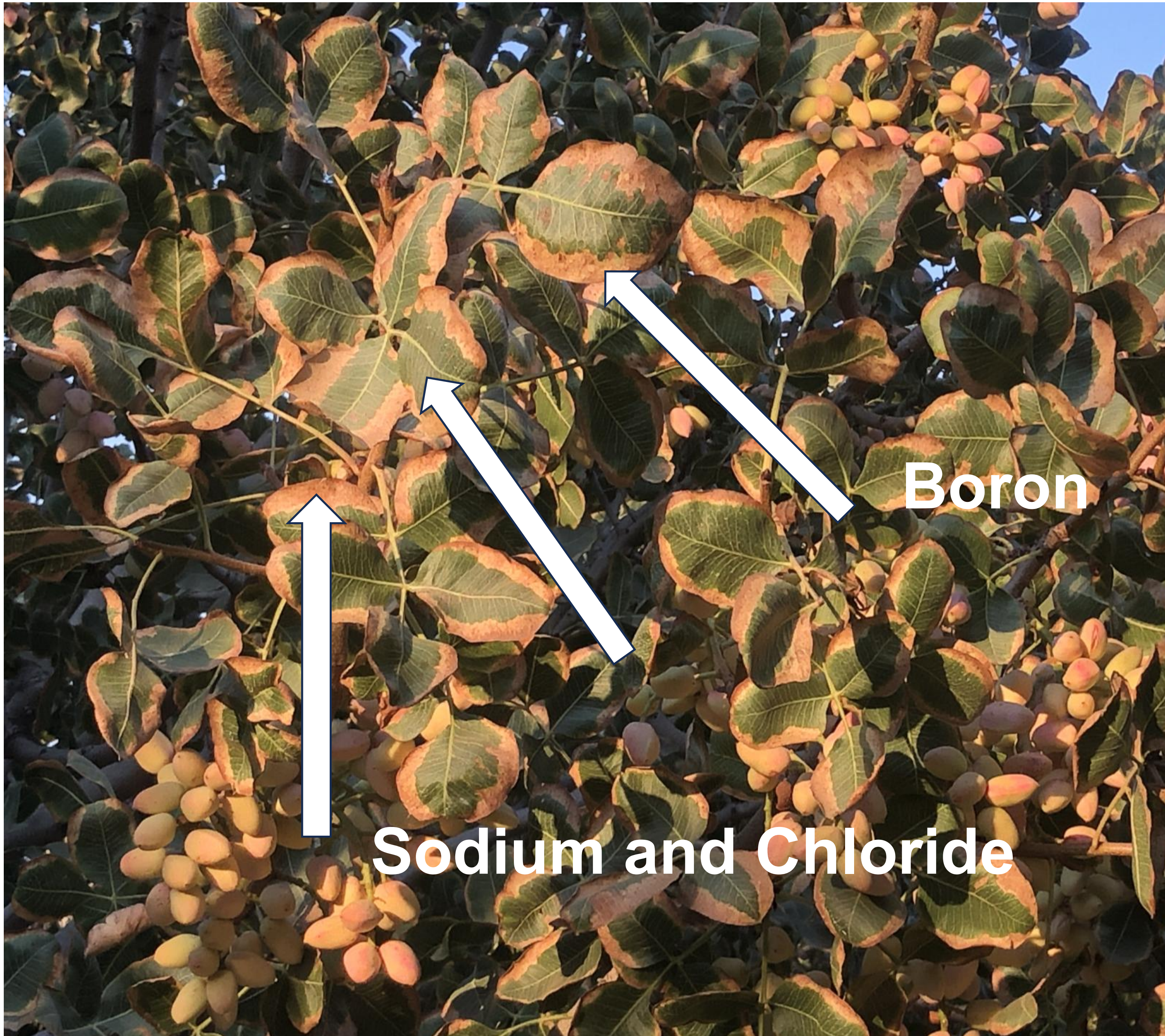
B (H_3BO_3 (boric acid) and $H_2BO_3^{-}$ (borate)

Pistachio salinity (in)tolerance appears as…

osmotic pressure and specific ion damage

Micronutrient boron creates most specific ion damage…

12/18/2025



Effects of salinity on Pistachio yield….

Specific Ion toxicity

Nutrient Imbalances

< soil osmotic potential

Higher Energy cost

Degradation of soil structure

Root hypoxia and anoxia

Water stress

Reduced Assimilation

Reduced growth

Reduced yield

Salt Tolerance

- **Greenhouse study conducted by L. Ferguson (2001) shows that osmotic effects are greater than specific ion effects**
  - ***P. integerrima*** **rootstocks less tolerant of salt-affected rootzones than** ***P. atlantica*** **or the hybrids.**
- **Established trees can be irrigated with water up to 8 dS/m (rootzone salinity of 11.4 dS/m) without affecting yield (B. Sanden, 2004)**
- **Salt tolerance when establishing orchards is lower (5 dS/m) (B. Sanden, L. Ferguson 2014)**

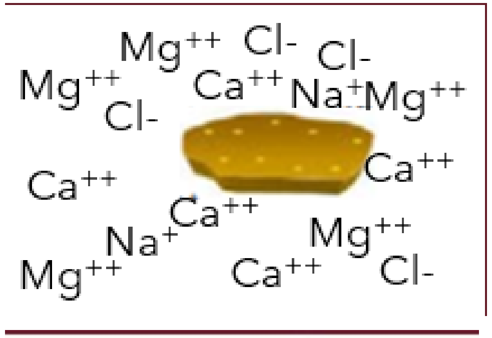
Key things to look for in water and soil analyses:

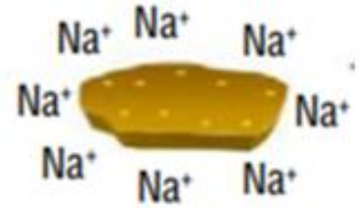
Analysis	Threshold for caution
pH	> 7.5 acidifying amendments likely necessary
EC (dS/m)	> 4.5 water, > 6-8 soil (potential reduced vigor and production)
Na^+ and Cl^- (meq./L)	> 20* soil and water
Boron (mg/L)	> 2 soil and water
SAR water	> 5x EC_w likely infiltration problems
Exchangeable sodium % soil	> 4% likely infiltration problems
Bicarbonates (HCO_3^-) water (meq./L)	> 2.5, acid forming amendments recommended
% Lime ($CaCO_3^-$) soil	<1% add Ca amendments, >1% use acid forming amendments

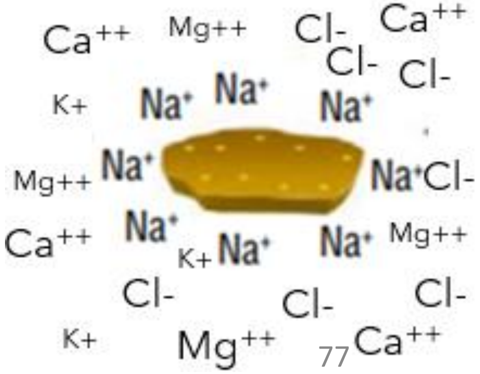
*Sanden, B.L., L. Ferguson, H.C. Reyes, and S.C. Grattan. 2004.

Saline, Sodic, Saline-sodic soil…..

- **Saline conditions:** pH < 8.5, elevated salts but generally low Na. Can cause osmotic stress and nutrient imbalances, water infiltrates normally
- **Sodic conditions:** pH> 8.5, overall dissolved salts are low, but exchangeable Na levels are high enough to deteriorate soil structure and impact water infiltration
- **Saline-sodic conditions:** pH<8.5, overall dissolved salts high and exchangeable sodium levels are high







Summary of Salinity Management:

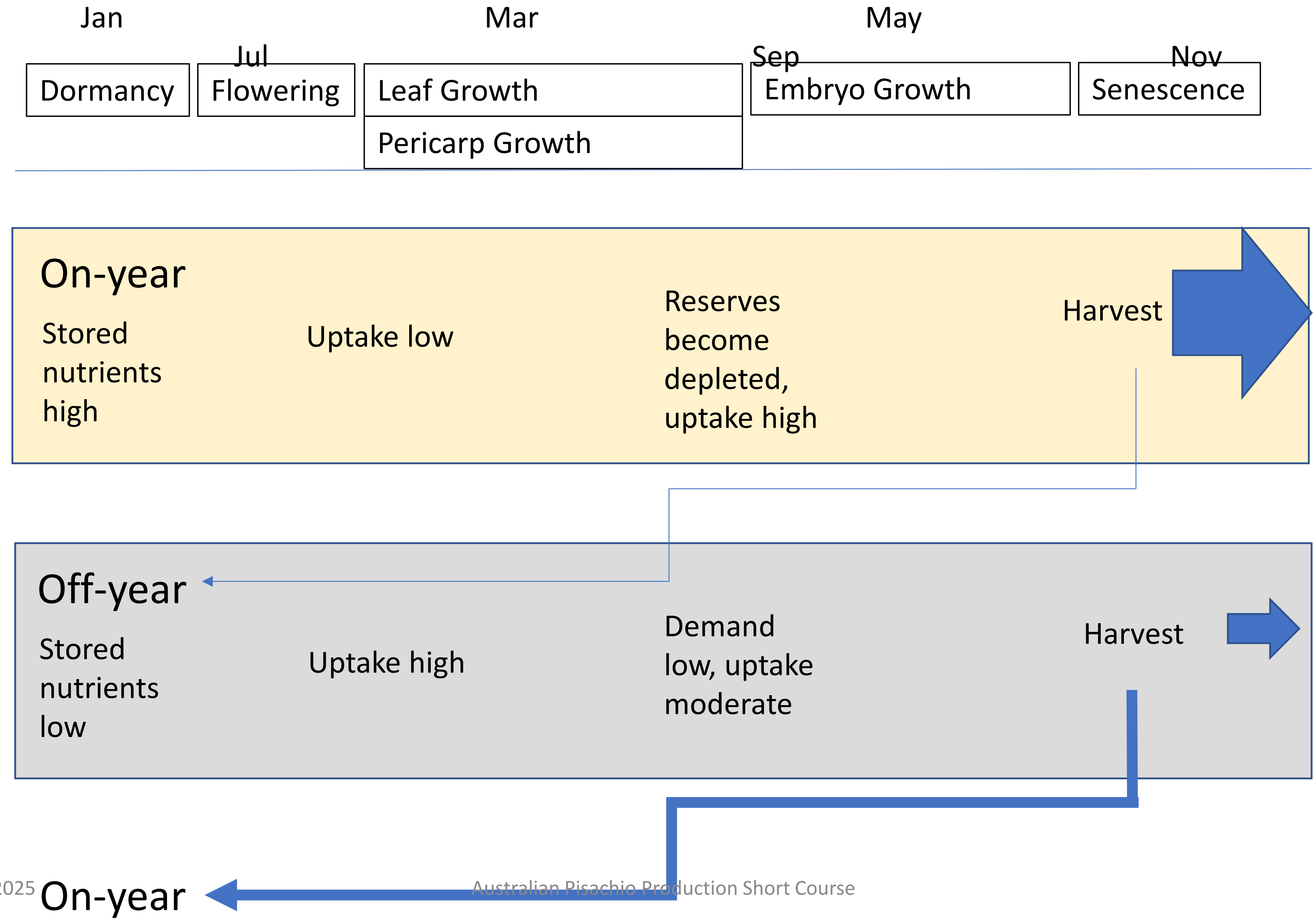
- Sample soil and water to make sure conditions (sodic or saline sodic) warrant amendments, saline conditions may possibly be mitigated with leaching alone.
- In general, soil applications address root zone problems and injected amendments treat shallow sodic surface conditions.
- Careful with over application, can make problems worse
- Annual cover crops are beneficial for water infiltration and may be worth trade-offs
- Post amendment reclamation leaching is critical
- Experimentally:
  - double line was best for leaching in season
  - In-season + pulsed winter is best for leaching
  - soil boron levels, but not leaf boron levels or leaf damage, correlated with yield decline

Drought Tolerance

- **Phreatophytes**
  - **Can exploit deep reservoirs of water**
- **Leaves adapted to maintain turgor in arid conditions**
  - **Thick cuticle**
  - **Xerophytic palisade mesophyll adaptation**
  - **More abaxial stomata than adaxial**
  - **Stomatal conductance higher on abaxial side**
  - **Stomata located near leaf veins**
  - **Can adjust stomata size and density (Marino, 2025)**

Pistachio Nutrient Uptake:

- Pistachios take up nutrients at a rate reflecting demand
- No uptake during dormancy
- Little uptake between harvest and leaf senescence
- Fruit shows strong demand for nutrients
  - High uptake during nut fill…potassium
- Higher uptake during on years than off
  - Accumulation mostly in fruit in on-year trees, perennial tissues in off years


Jan
Jul
Mar
Sep
May
Nov
Dormancy
Flowering
Leaf Growth
Pericarp Growth
Embryo Growth
Senescence
On-year
Stored nutrients high
Uptake low
Reserves become depleted, uptake high
Harvest
Off-year
Stored nutrients low
Uptake high
Demand low, uptake moderate
Harvest
On-year

Components of yield =

- #clusters x #nuts/cluster x nut weight x nut quality

Carbohydrate storage in stems and trunks, bud abscission

Water, carbohydrates

Blanks, kernel abortion, nut removal at harvest

Early split and non-split

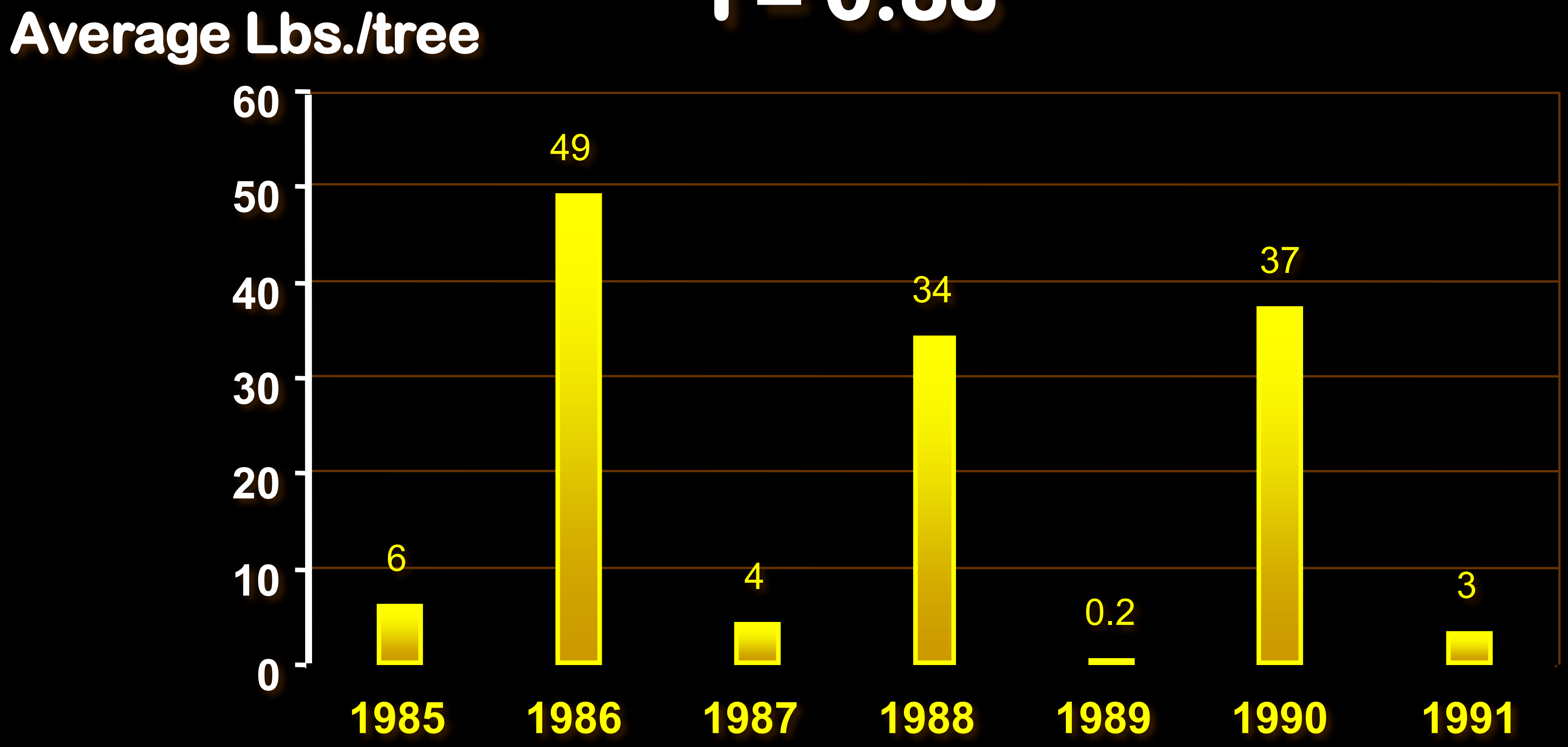
Future

Current- year

Alternate Bearing

- **Alternate Bearing Index:**
- **1 = total alternate bearing**
- **0 = equal crops annually**

Alternate Bearing in Kern County 1985 – 1991 I = 0.88





Severe mechanical topping and hedging stimulates strong vegetative growth and produces a better ratio of bearing:nonbearing shoot growth

7 Year Yield Response
Kerman on *P. atlantica* rootstock

- <u>Hedged and Topped</u>
- 1985: 0.8 kg/tree
- 1986: 12.7 kg/tree ON!
- 1987: 6.4 kg/tree
- 1988: 11.8/kg/tree ON!
- 1989: 5.1/kg/tree
- 1990: 12.2/kg/tree ON!
- 1991: 11.6/kg/tree
- <u>60.6/kg/tree cumulative</u>

- <u>Control</u>
- 1985: 2.9 kg/tree OFF!
- 1986: 22.1 kg/tree
- 1987: 1.6 kg/tree OFF!
- 1988: 15.3/kg/tree
- 1989: 0.1/kg/tree OFF!
- 1990: 16.7/kg/tree
- 1991: 1.4/kg/tree OFF!
- <u>60.1/kg/tree cumulative</u>

•Results:

Mechanical topping mitigated alternate bearing by producing a better ratio of bearing : non-bearing shoots.

- **Topping was more effective than hedging**
- **Was more effective entering the <u>low crop year</u>**

HORTSCIENCE 30(7): 1369-1372. 1995.

Mechanical Topping Mitigates Alternate Bearing of 'Kerman' Pistachios *(Pistacia vera* L.)

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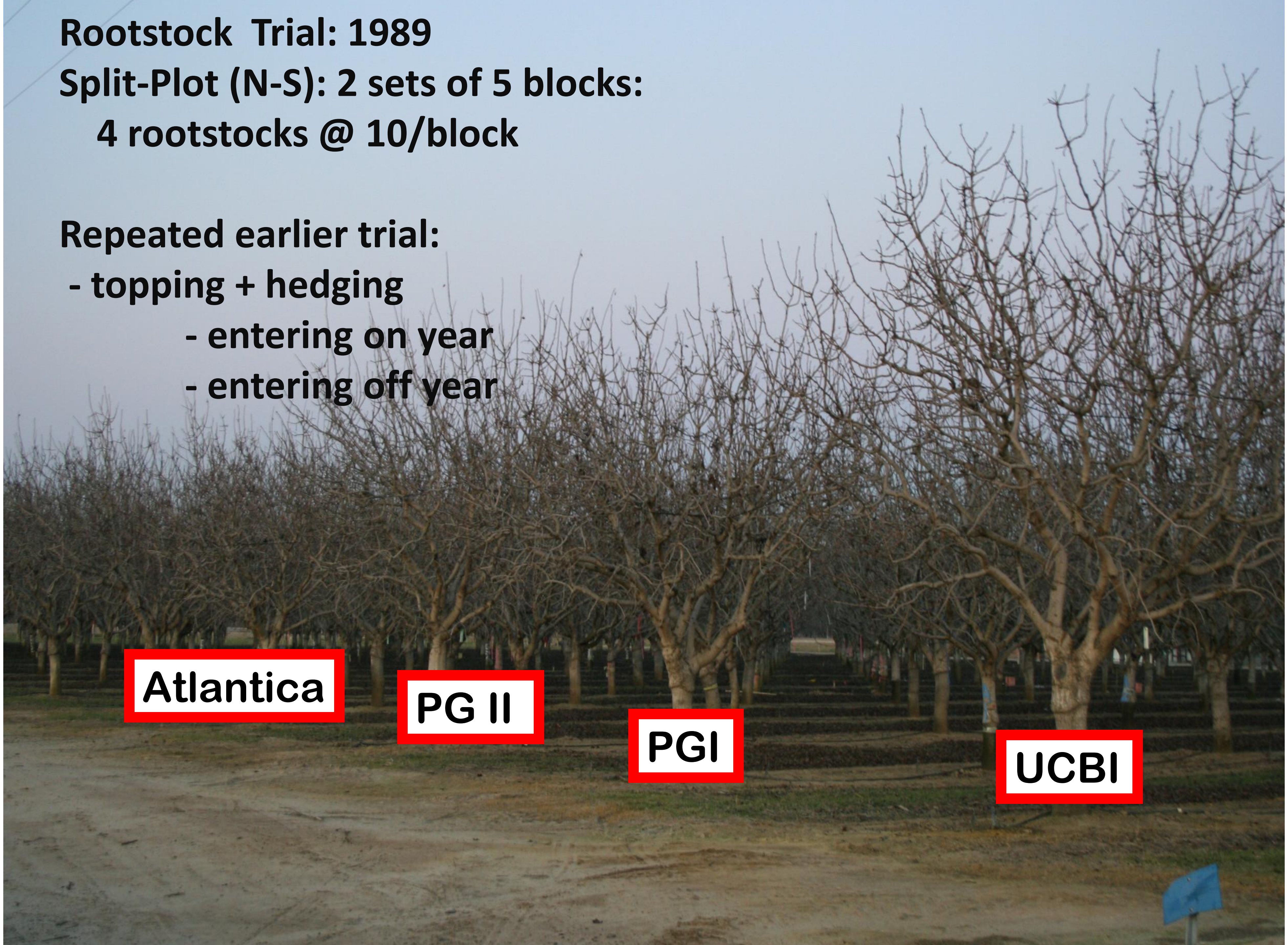
Additional index words. Pistacia atlantica, hedging, pruning, nut quality, blanks, shell splitting


CAT
ATL
R-4
ATL
R-5
Huge


Rootstock Trial: 1989
Split-Plot (N-S): 2 sets of 5 blocks:
4 rootstocks @ 10/block
Repeated earlier trial:
- topping + hedging
- entering on year
- entering off year
Atlantica
PG II
PGI
UCBI

Rootstock	Topped & Hedged	Alternate Bearing Index	Lbs./Acre @ 128 trees/acre
P. Atlantica	ON	.79	3552
P. Atlantica	OFF	.41	4049 (3823)
P. Integerrima	ON	.55	4538
P. Integerrima	OFF	.21	4924 (4731)
P. Integerrima X P. Atlantica	ON	.27	5442
P. Integerrima X P. Atlantica	OFF	.27	5425 (5433)
P. Atlantica X P. Integerrima	ON	.29	5445
P. Atlantica X P. Integerrima	OFF	.30	5823 (5634)

•Conclusions and Implications:

- **1995 databased conclusion was correct for trees on species rootstocks:**
  - ***P. Atlantica***
  - ***P. Integerrima***

  - **Mechanical pruning entering the off year altered the ratio of bearing to nonbearing shoots:**
    - **Mitigating the alternate bearing intensity**
    - **Without addressing the mechanism**

•Conclusions and Implications:

- 1995 databased conclusion NOT correct for trees on hybrid rootstocks:
  - *P. Atlantica x P. Integerrima* = UCBI
  - *P. Integerrima X P. Atlantica* = PGII or Platinum ®

- Rootstock vigor affected alternate bearing index by ?
  - neoformed shoot growth, most removed by dormant pruning, provided additional leaf surface area for additional carbohydrate production and storage to:
    - decrease bud abscission?
      - not supported by current data
    - better support remaining buds?

Conclusion:

- In next two days we hope to discuss what we have learned and and how it may apply to your industry…