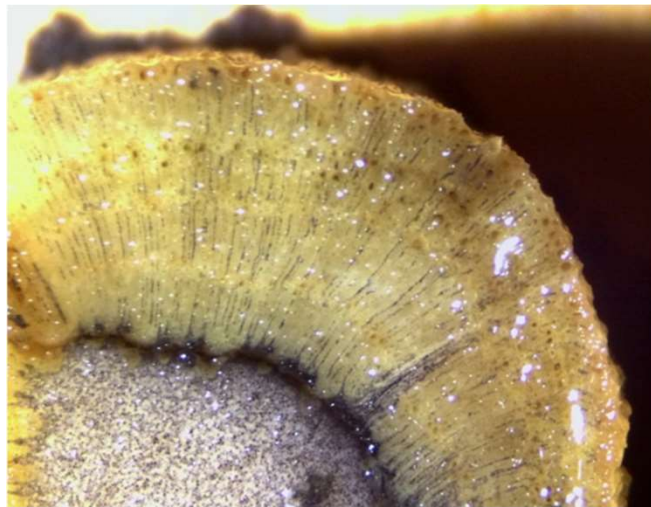


From Physiology to Practice Integrating Seasonal Dynamics of Non-Structural Carbohydrates into Orchard Management

Maciej Zwieniecki
UC Davis, California, USA



>99% of plant material is built from three main elements.



Carbon C



Hydrogen H



Oxygen O

$(\text{CH}_2\text{O})_n$ - carbohydrates (sugars)

Where does all that CH_2O come from?

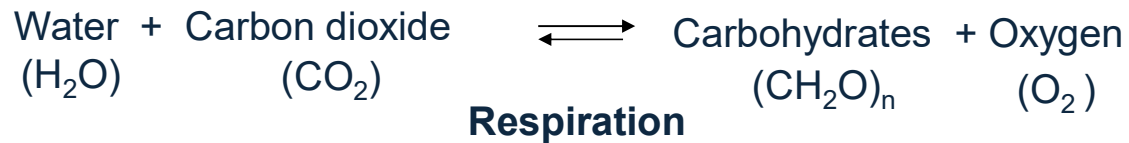
PHOTOSYNTHESIS

The energy is stored in carbon bonds created during photosynthesis and liberated during respiration.

Photosynthesis is the process by which plants capture the energy in sunlight and convert it to a biologically usable form.

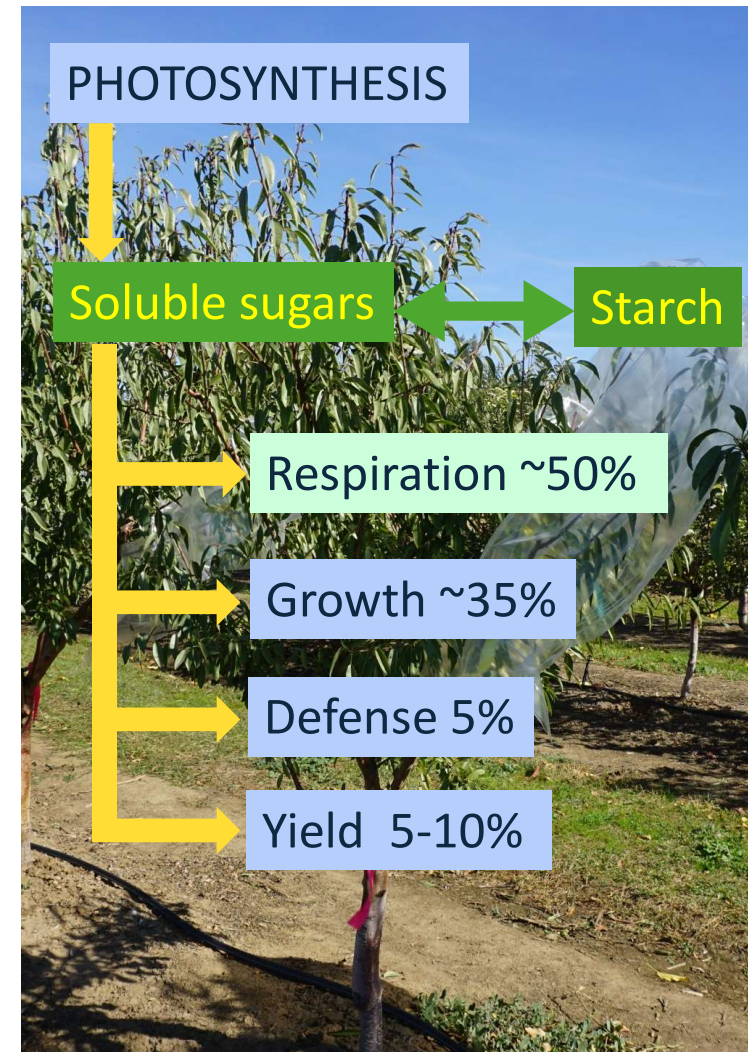
Solar energy absorbed
by chlorophyll

↓
Photosynthesis



Physiology of carbohydrates. management in nut trees

- Carbohydrates provides energy for maintenance, growth, defense, and reproduction (yield)
- Carbohydrates are only being produced during day (sunlight) and only when leaves are on the trees but used 24 hour a day and 365(6) days a year.
- Non-Structural Carbohydrates (NSC) are the tree's liquid assets - 'currency' they are in two forms (1) soluble sugars and (2) starches.
- Soluble carbohydrates can be considered as 'cash' that flows around the tree. Starch is the 'currency' saving account.
- Trees continuously measure soluble sugar levels (measure cash in hand) and supplement it from starch (savings) or recharge savings if it has overflow of sugar (cash).
- **NSC level has to be maintained to allow trees to survive and recover after non-photosynthetic periods: daily (night) and seasonally (dormancy)**



Orchard management focus is on facilitating photosynthetic activity:

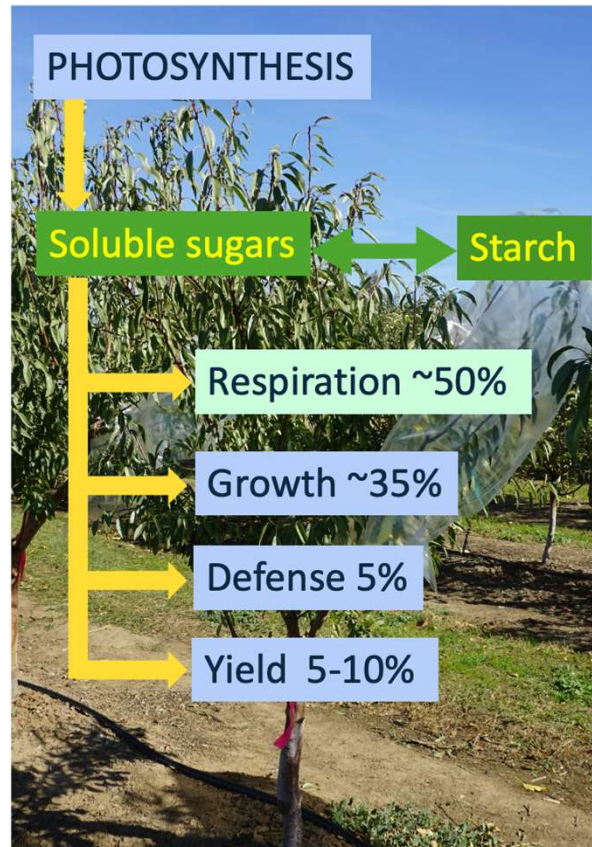
- irrigation
- fertilization

Boosting amount of carbohydrates

and protection from:

- insects
- pathogens
- diseases

Reducing cost of defense



Respiration is temperature dependent

We can not do much about it

Growth is the function of available NSC, space, physiological needs

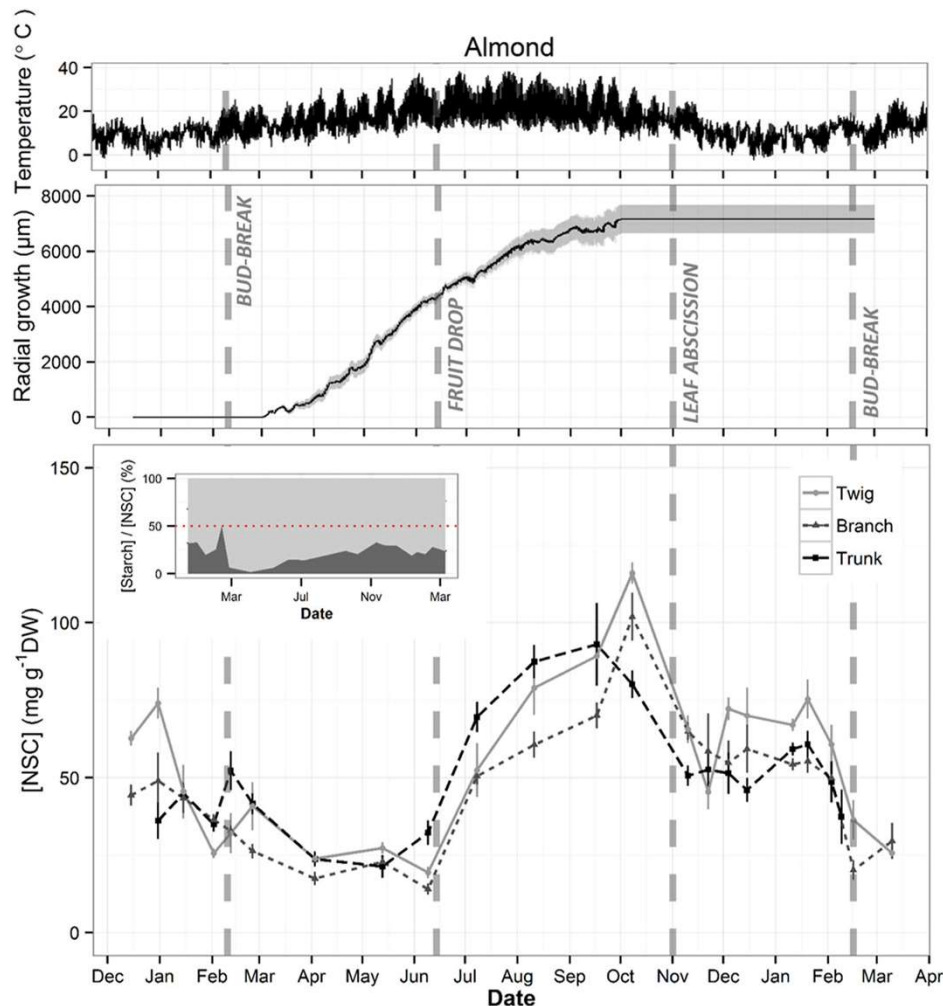
We can not tell plant how to grow

Investment in reproduction is a function of initiated embryos, NSC availability and evolved redistribution function

We have very little impact on forcing plant to change its evolved behavior

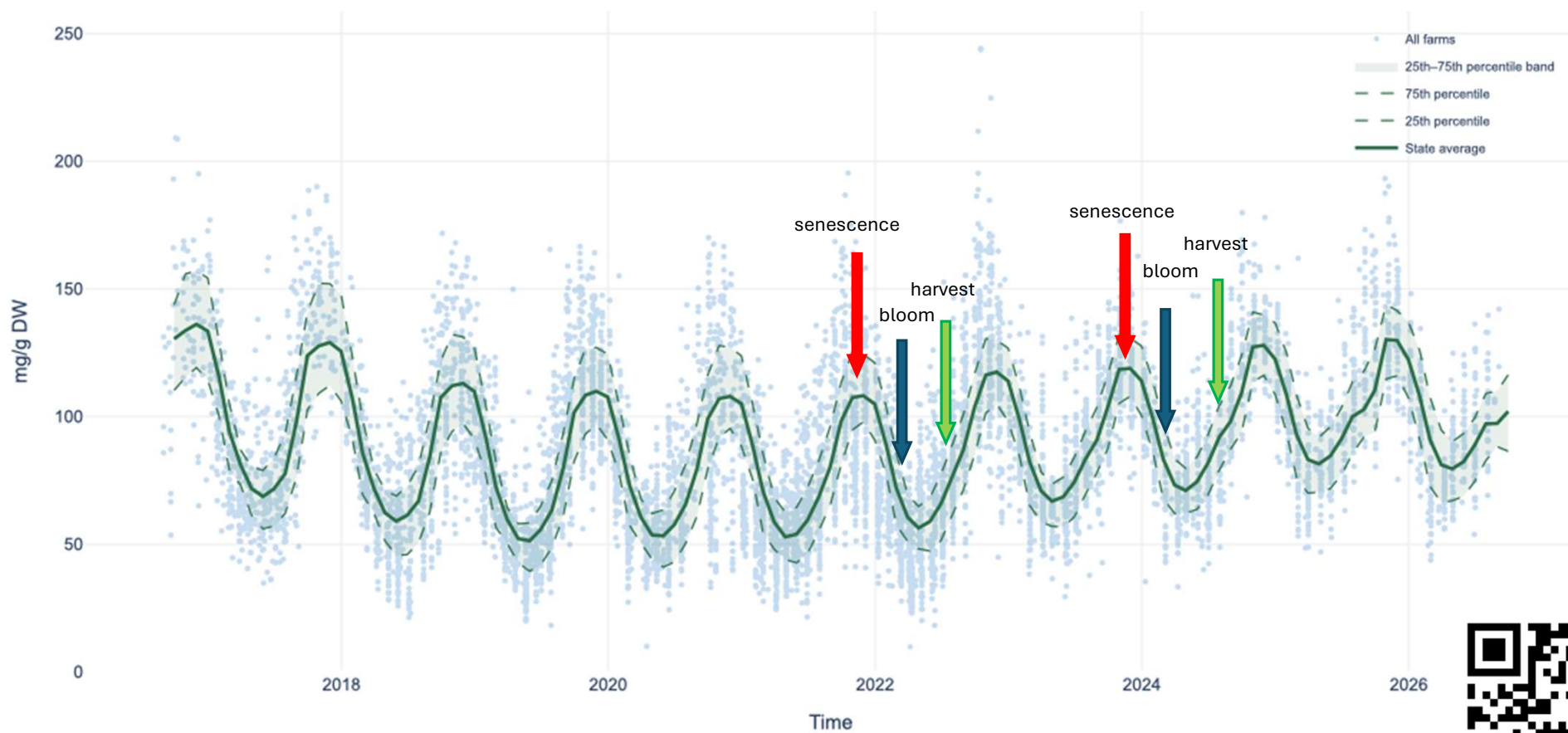
Knowing when and how plant makes decision on use of its NSC investment can provide means to increase orchards productivity

Lets look at a typical seasonal dynamics of non-structural carbohydrate content of nut trees in relation to girth growth and flowering, in Central Valley, CA (pistachio)

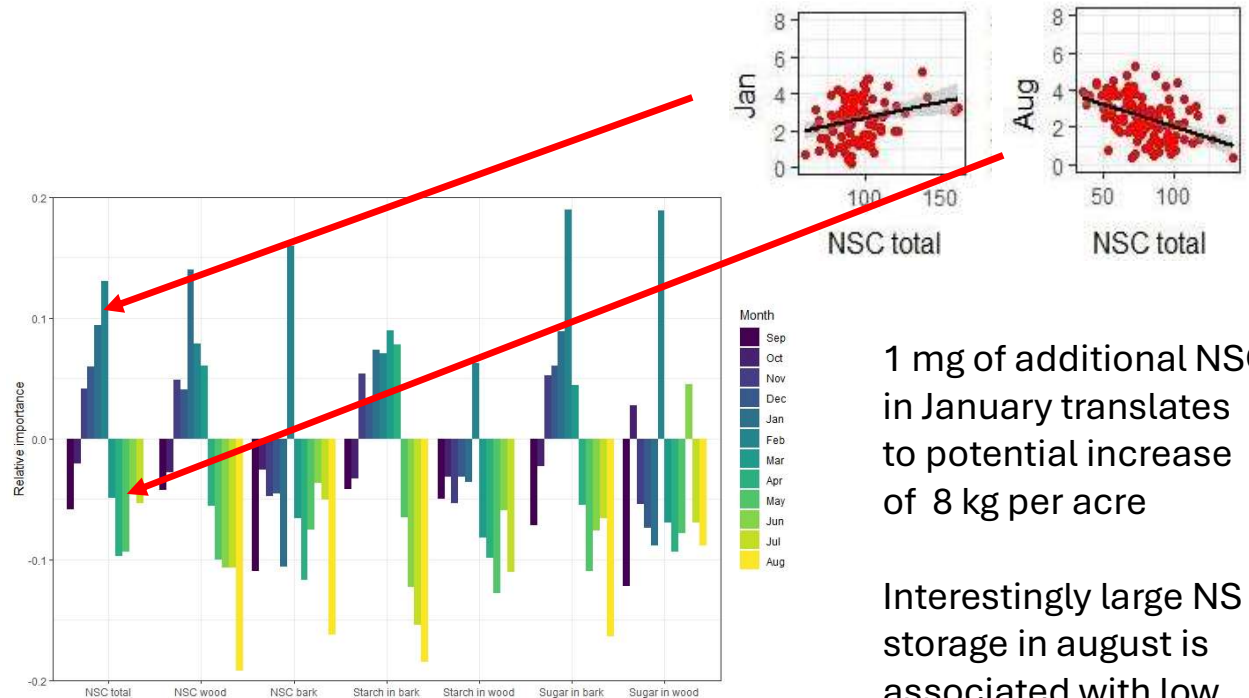
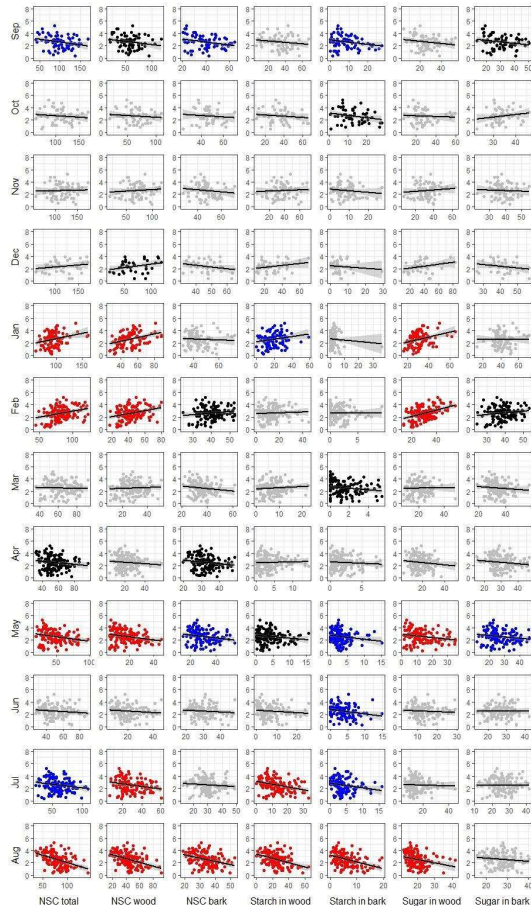


- NSC content is highly dynamic over the season in trees – **trends and composition of NSC provides information on tree health and future performance**
- Most significant drain of NSC reserves occurs during dormancy and post bud break - **pre-winter starch accumulation is a prerequisite for healthy spring growth.**
- Fall NSC content correlates with following year yield, low summer NSC content correlates with high yield - **a fall (post-harvest) orchard management practices are crucial for the recovery of the NSC reserves. Most likely we can design these practices to most effectively prepare trees for the dormancy**

NSC content multi-year pattern - phenology



Studying impact of NSC content on yield



1 mg of additional NSC in January translates to potential increase of 8 kg per acre

Interestingly large NS storage in august is associated with low yield 1mg of unused NSC leads to 10 kg yield reduction.

Correlation between NSC and yield

Yield
2025

R² — NSC vs NP Yield | 1-Year Lag (Lag=1) | All Years
(+/- = correlation direction | blue border = p < 0.05)

NSC Variable	2024												2025							
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
NSC_total	-0.00 p=0.747 RMSE=961	+0.00 p=0.478 RMSE=966	-0.00 p=0.812 RMSE=961	-0.05 p=0.002 RMSE=934	-0.22 p=0.000 RMSE=845	-0.26 p=0.000 RMSE=828	-0.31 p=0.000 RMSE=805	-0.19 p=0.000 RMSE=868	-0.06 p=0.001 RMSE=939	-0.03 p=0.029 RMSE=954	-0.01 p=0.170 RMSE=966	-0.01 p=0.007 RMSE=962	-0.03 p=0.007 RMSE=951	-0.03 p=0.008 RMSE=948	-0.03 p=0.012 RMSE=939	-0.10 p=0.000 RMSE=903	-0.25 p=0.000 RMSE=824	-0.31 p=0.000 RMSE=798	-0.32 p=0.000 RMSE=763	-0.28 p=0.000 RMSE=816
NSC_wood	+0.00 p=0.496 RMSE=962	+0.01 p=0.107 RMSE=960	+0.01 p=0.216 RMSE=957	-0.03 p=0.018 RMSE=944	-0.18 p=0.000 RMSE=870	-0.18 p=0.000 RMSE=867	-0.24 p=0.000 RMSE=846	-0.13 p=0.000 RMSE=900	-0.03 p=0.015 RMSE=951	-0.00 p=0.654 RMSE=966	+0.00 p=0.822 RMSE=971	-0.00 p=0.785 RMSE=967	-0.01 p=0.128 RMSE=960	-0.01 p=0.200 RMSE=960	-0.01 p=0.101 RMSE=947	-0.10 p=0.000 RMSE=906	-0.22 p=0.000 RMSE=839	-0.23 p=0.000 RMSE=842	-0.34 p=0.000 RMSE=775	-0.24 p=0.000 RMSE=840
NSC_bark	-0.04 p=0.006 RMSE=941	-0.02 p=0.090 RMSE=959	-0.08 p=0.000 RMSE=923	-0.07 p=0.000 RMSE=926	-0.24 p=0.000 RMSE=834	-0.29 p=0.000 RMSE=806	-0.23 p=0.000 RMSE=848	-0.16 p=0.000 RMSE=886	-0.06 p=0.001 RMSE=938	-0.09 p=0.000 RMSE=923	-0.09 p=0.000 RMSE=925	-0.08 p=0.000 RMSE=929	-0.10 p=0.000 RMSE=917	-0.12 p=0.000 RMSE=906	-0.05 p=0.001 RMSE=928	-0.06 p=0.000 RMSE=923	-0.23 p=0.000 RMSE=838	-0.33 p=0.000 RMSE=775	-0.23 p=0.000 RMSE=846	-0.16 p=0.000 RMSE=883
sugar_wood_avg	+0.00 p=0.777 RMSE=963	+0.02 p=0.046 RMSE=956	+0.01 p=0.320 RMSE=959	-0.01 p=0.209 RMSE=955	-0.05 p=0.002 RMSE=933	-0.05 p=0.000 RMSE=934	-0.11 p=0.000 RMSE=910	-0.08 p=0.000 RMSE=929	-0.04 p=0.007 RMSE=948	-0.00 p=0.573 RMSE=966	+0.00 p=0.702 RMSE=971	-0.02 p=0.000 RMSE=960	-0.02 p=0.032 RMSE=955	-0.00 p=0.339 RMSE=961	-0.02 p=0.046 RMSE=944	-0.07 p=0.000 RMSE=919	-0.12 p=0.000 RMSE=892	-0.12 p=0.000 RMSE=900	-0.23 p=0.000 RMSE=843	-0.21 p=0.000 RMSE=859
starch_wood_avg	+0.01 p=0.333 RMSE=960	+0.00 p=0.447 RMSE=965	+0.01 p=0.221 RMSE=957	-0.07 p=0.000 RMSE=925	-0.31 p=0.000 RMSE=805	-0.24 p=0.000 RMSE=836	-0.27 p=0.000 RMSE=828	-0.13 p=0.000 RMSE=900	-0.01 p=0.101 RMSE=960	-0.00 p=0.765 RMSE=967	+0.00 p=0.977 RMSE=971	+0.01 p=0.216 RMSE=963	-0.00 p=0.598 RMSE=964	-0.01 p=0.154 RMSE=959	-0.00 p=0.449 RMSE=952	-0.10 p=0.000 RMSE=905	-0.26 p=0.000 RMSE=822	-0.24 p=0.000 RMSE=839	-0.35 p=0.000 RMSE=755	-0.16 p=0.000 RMSE=881
sugar_bark_avg	-0.03 p=0.014 RMSE=945	-0.01 p=0.292 RMSE=964	-0.04 p=0.009 RMSE=943	-0.03 p=0.015 RMSE=943	-0.17 p=0.000 RMSE=874	-0.17 p=0.000 RMSE=873	-0.07 p=0.000 RMSE=933	-0.07 p=0.000 RMSE=931	+0.00 p=0.956 RMSE=967	-0.02 p=0.063 RMSE=958	-0.01 p=0.134 RMSE=965	-0.01 p=0.131 RMSE=961	-0.07 p=0.000 RMSE=934	-0.08 p=0.000 RMSE=926	-0.03 p=0.014 RMSE=940	-0.01 p=0.089 RMSE=946	-0.12 p=0.000 RMSE=891	-0.19 p=0.000 RMSE=866	-0.04 p=0.002 RMSE=943	-0.05 p=0.001 RMSE=938
starch_bark_avg	-0.00 p=0.667 RMSE=960	-0.01 p=0.124 RMSE=961	-0.04 p=0.008 RMSE=943	-0.06 p=0.001 RMSE=929	-0.17 p=0.000 RMSE=876	-0.23 p=0.000 RMSE=840	-0.18 p=0.000 RMSE=877	-0.10 p=0.000 RMSE=917	-0.09 p=0.000 RMSE=922	-0.08 p=0.000 RMSE=928	-0.11 p=0.000 RMSE=914	-0.12 p=0.000 RMSE=904	-0.01 p=0.084 RMSE=960	-0.03 p=0.006 RMSE=947	-0.02 p=0.031 RMSE=943	-0.11 p=0.000 RMSE=899	-0.20 p=0.000 RMSE=854	-0.31 p=0.000 RMSE=798	-0.23 p=0.000 RMSE=848	-0.11 p=0.000 RMSE=906
sugar_branch	-0.00 p=0.342 RMSE=959	+0.00 p=0.351 RMSE=965	-0.00 p=0.698 RMSE=961	-0.02 p=0.045 RMSE=948	-0.11 p=0.000 RMSE=905	-0.12 p=0.000 RMSE=899	-0.15 p=0.000 RMSE=893	-0.11 p=0.000 RMSE=914	-0.02 p=0.038 RMSE=956	-0.01 p=0.218 RMSE=963	-0.00 p=0.764 RMSE=971	-0.02 p=0.062 RMSE=958	-0.05 p=0.001 RMSE=943	-0.03 p=0.013 RMSE=950	-0.03 p=0.006 RMSE=937	-0.06 p=0.000 RMSE=925	-0.15 p=0.000 RMSE=877	-0.19 p=0.000 RMSE=867	-0.21 p=0.000 RMSE=858	-0.19 p=0.000 RMSE=864
starch_branch	+0.00 p=0.489 RMSE=960	+0.00 p=0.898 RMSE=967	+0.00 p=0.952 RMSE=961	-0.09 p=0.000 RMSE=915	-0.30 p=0.000 RMSE=804	-0.27 p=0.000 RMSE=817	-0.30 p=0.000 RMSE=808	-0.18 p=0.000 RMSE=873	-0.06 p=0.001 RMSE=939	-0.03 p=0.016 RMSE=952	-0.03 p=0.030 RMSE=959	-0.00 p=0.582 RMSE=966	-0.00 p=0.308 RMSE=965	-0.02 p=0.037 RMSE=954	-0.01 p=0.157 RMSE=949	-0.15 p=0.000 RMSE=878	-0.29 p=0.000 RMSE=804	-0.31 p=0.000 RMSE=797	-0.36 p=0.000 RMSE=748	-0.21 p=0.000 RMSE=857
NSC_wood_fraction	+0.00 p=0.496 RMSE=962	+0.01 p=0.107 RMSE=960	+0.01 p=0.216 RMSE=957	-0.03 p=0.018 RMSE=944	-0.18 p=0.000 RMSE=870	-0.18 p=0.000 RMSE=867	-0.24 p=0.000 RMSE=846	-0.13 p=0.000 RMSE=900	-0.03 p=0.015 RMSE=951	-0.00 p=0.654 RMSE=966	+0.00 p=0.822 RMSE=971	-0.00 p=0.785 RMSE=967	-0.01 p=0.128 RMSE=960	-0.01 p=0.200 RMSE=960	-0.01 p=0.101 RMSE=947	-0.10 p=0.000 RMSE=906	-0.22 p=0.000 RMSE=839	-0.23 p=0.000 RMSE=842	-0.34 p=0.000 RMSE=775	-0.24 p=0.000 RMSE=840
NSC_bark_fraction	-0.04 p=0.006 RMSE=941	-0.02 p=0.090 RMSE=959	-0.08 p=0.000 RMSE=923	-0.07 p=0.000 RMSE=926	-0.24 p=0.000 RMSE=834	-0.29 p=0.000 RMSE=806	-0.23 p=0.000 RMSE=848	-0.16 p=0.000 RMSE=886	-0.06 p=0.001 RMSE=938	-0.09 p=0.000 RMSE=923	-0.09 p=0.000 RMSE=925	-0.08 p=0.000 RMSE=929	-0.10 p=0.000 RMSE=917	-0.12 p=0.000 RMSE=906	-0.05 p=0.001 RMSE=928	-0.06 p=0.000 RMSE=923	-0.23 p=0.000 RMSE=838	-0.35 p=0.000 RMSE=775	-0.23 p=0.000 RMSE=846	-0.16 p=0.000 RMSE=883
sugar_wood_frac	+0.00 p=0.777 RMSE=963	+0.02 p=0.046 RMSE=956	+0.01 p=0.320 RMSE=959	-0.01 p=0.209 RMSE=955	-0.05 p=0.002 RMSE=933	-0.05 p=0.000 RMSE=934	-0.11 p=0.000 RMSE=910	-0.08 p=0.000 RMSE=929	-0.04 p=0.007 RMSE=948	-0.00 p=0.573 RMSE=966	+0.00 p=0.702 RMSE=971	-0.02 p=0.000 RMSE=960	-0.02 p=0.032 RMSE=955	-0.00 p=0.339 RMSE=961	-0.02 p=0.046 RMSE=944	-0.07 p=0.000 RMSE=919	-0.12 p=0.000 RMSE=892	-0.12 p=0.000 RMSE=900	-0.23 p=0.000 RMSE=843	-0.21 p=0.000 RMSE=859
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Practical implications

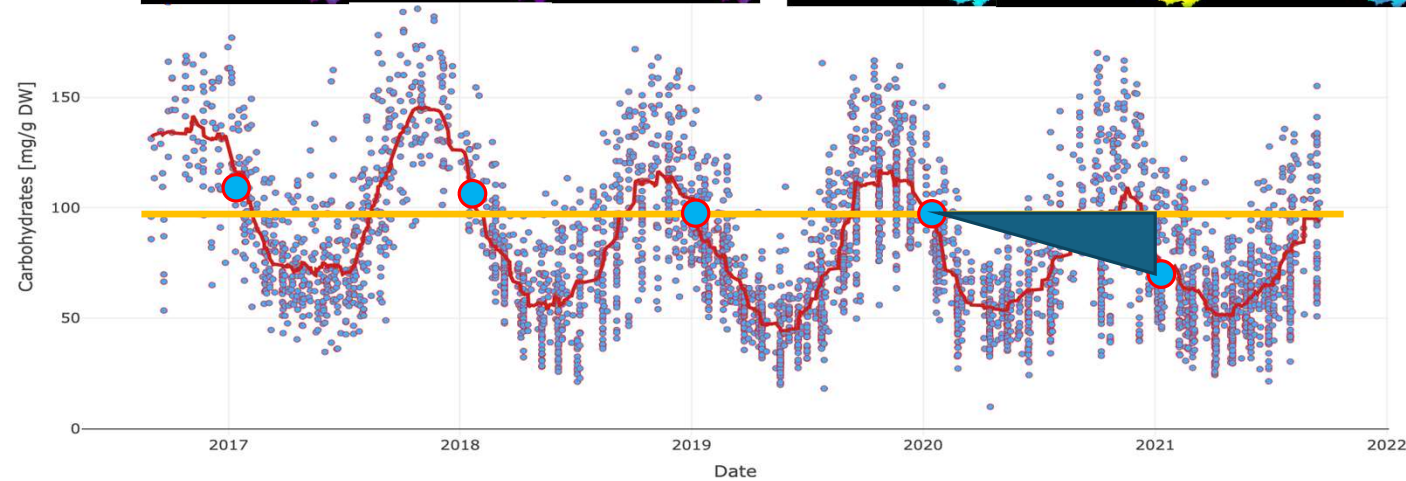
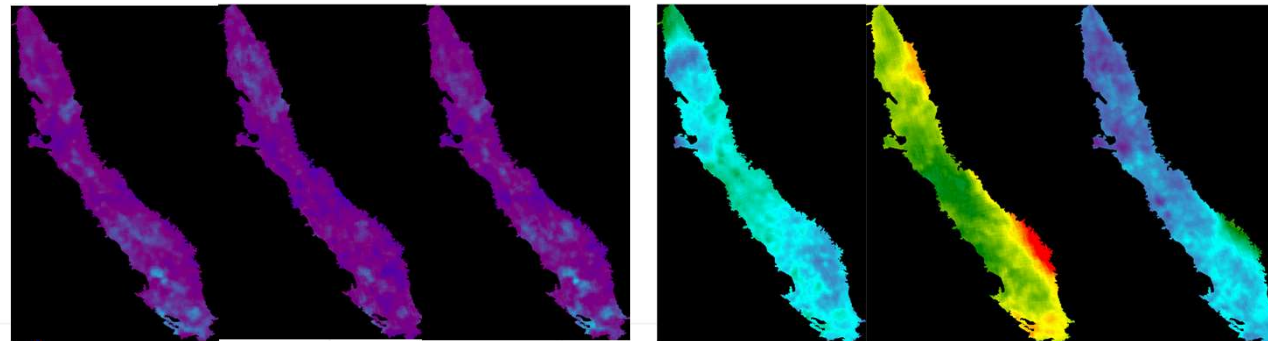
Any management practice or environmental parameter that has an effect on recovery of carbohydrates or their use can affect productivity (yield, health, etc)

Examples:

- Excessive heat in the winter forces use of NSC and may result in an uneven bloom, low pollination or delayed leafing out
 - Global warming
 - Chill substitutes
- Reduced photosynthetic activity during the growing season or parts of the growing season leading to temporal NSC starvation – low fertilization, problems with shell and embryos development, reduced number of healthy nodes for future spurs growth
 - Drought/irrigation
 - Fertigation
- Inadequate fall recovery – impact on dormancy and bloom time
 - Early leaf drop
 - Air quality (smoke from wild-fires)
 - Post harvest management

Impact of environmental conditions on yield - case study

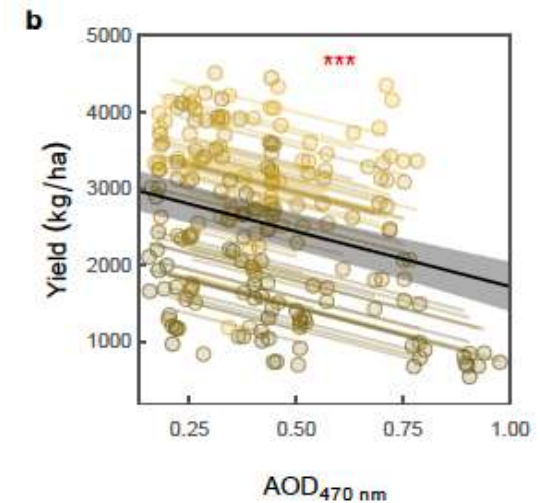
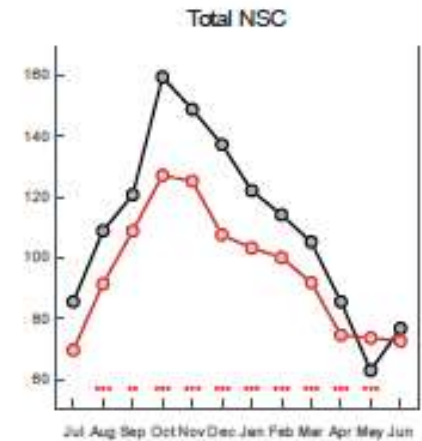
Monthly average smoke index value and its impact on NSC content (Sentinel 5)
(study by Jessica Orozco)



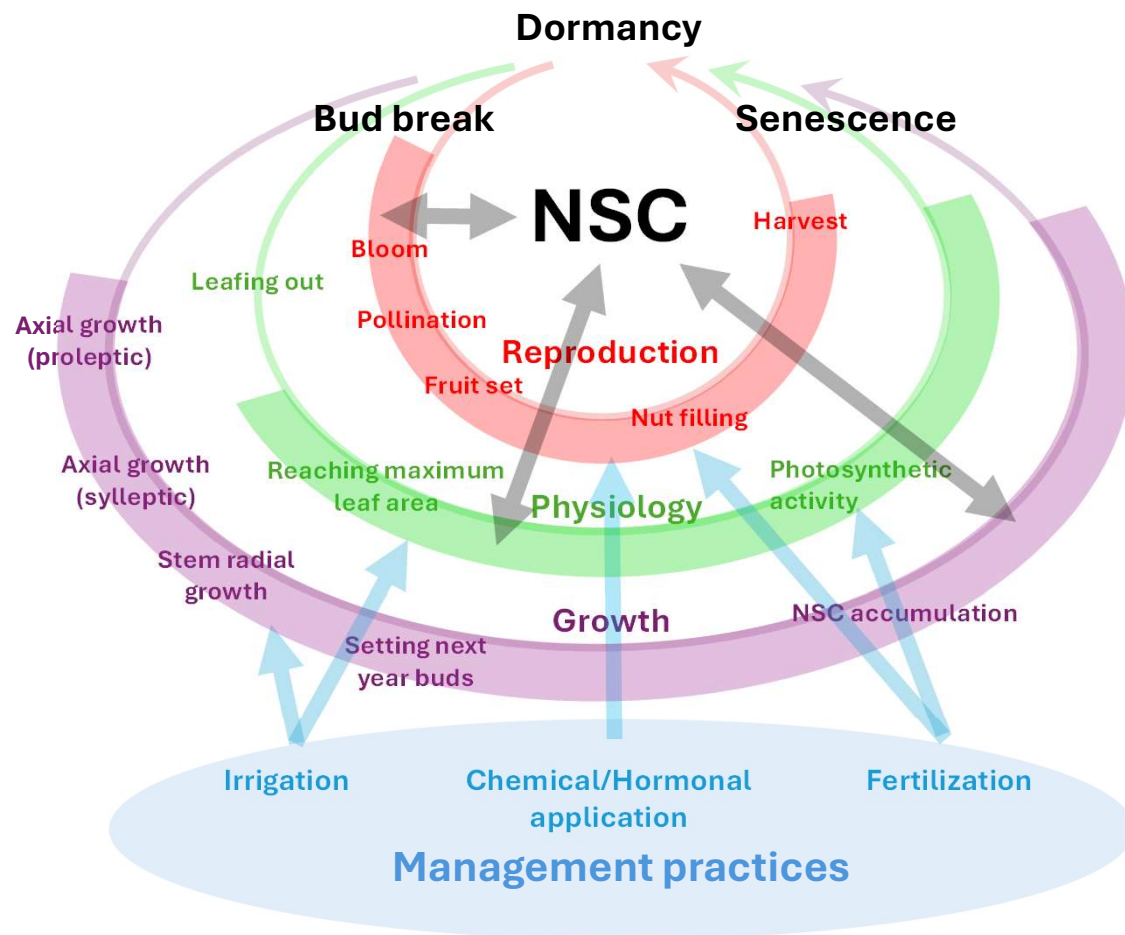
● January NSC level

Impact of smoke ~30 mg of NSC in January
Potential loss of 500 pounds per acre in 2021

Levels of AOD_{470 nm} — 0 — 1

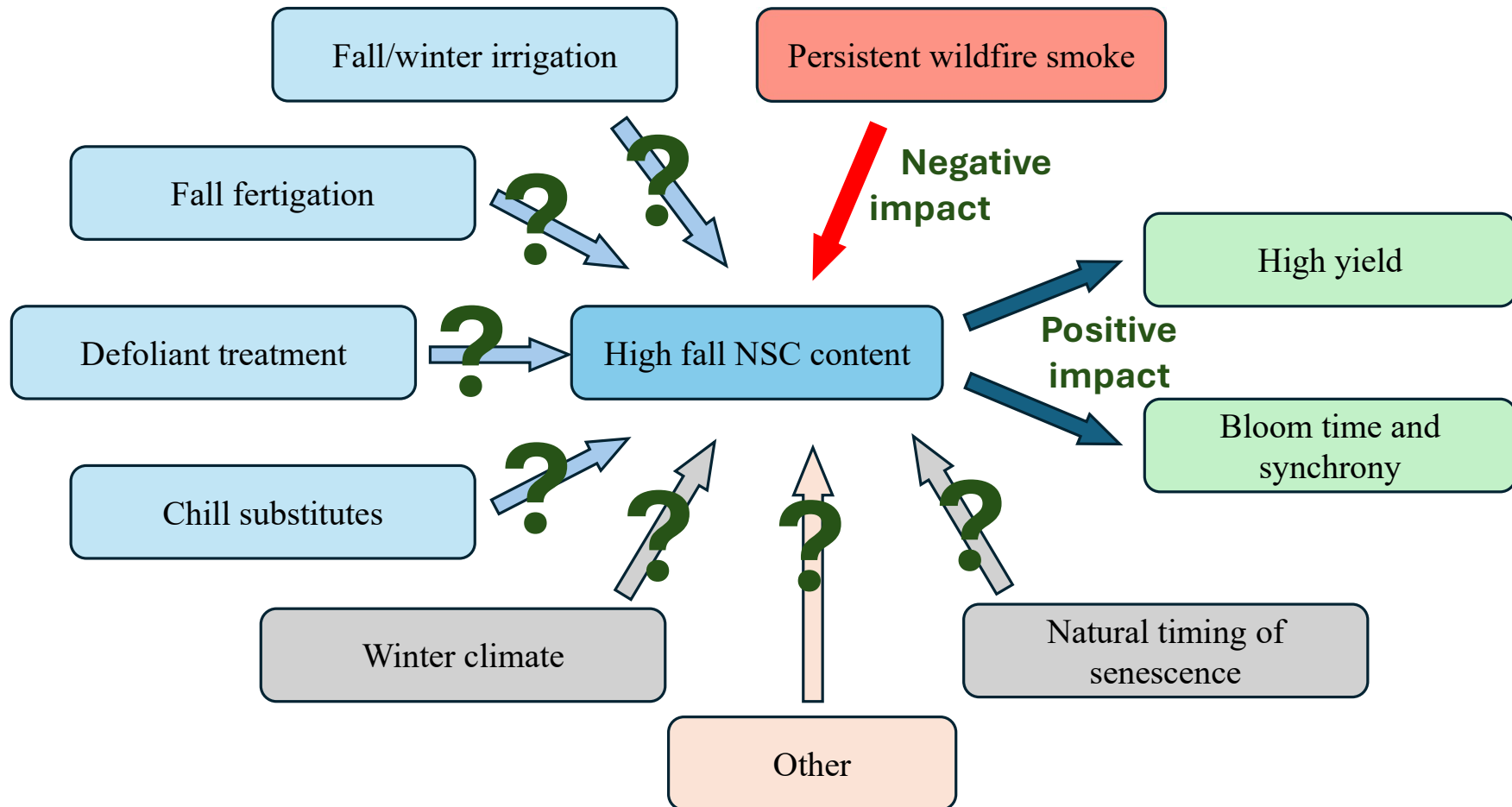


No matter what is the issue, the non-structural carbohydrates are at the center of it.



- Chilling hours
- Synchronous bloom
- Response to abiotic stresses
- Response to biotic stresses
- Irrigation
- Salinity
- Winter temperature
- Summer temperature
- Post harvest management
- Etc...

How to manipulate NSC?



Let's visit the Carbohydrate Observatory



<https://zlab-orchard.org/>

Thank you

“Tree is under no obligation to make sense to us”

Maciej Zwieniecki



Carbohydrate Observatory



<https://fruitsandnuts.ucdavis.edu/events/2027-principles-fruit-and-nut-tree-growth-cropping-and-management>

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- **Zwieniecki, MA.**, Davidson, AM., Orozco, J., Cooper, KB., Guzman-Delgado, P. 2021 The impact of non-structural carbohydrates (NSC) concentration on yield in *Prunus dulcis*, *Pistacia vera*, and *Juglans regia*. *Scientific Reports*. 4360. DOI10.1038/s41598-022-08289-8