Evaluating Growing Degree-Days as a Predictor for Cool-Season Crop Growth

Chelsea Maupin[1], Lilian Brislen[2], & Krista Jacobsen[1]

[1]Department of Horticulture, University of Kentucky

[2] The Food Connection, University of Kentucky

Images 1, 2, and 3, courtesy of Johnny's Selected Seeds (johnnyseeds.com)

INTRODUCTION

Novel farm-to-institution value chains provide a large market outlet for small-scale leafy greens farmers in central Kentucky. In 2019, 18,000lbs of locally sourced, seasonal produce that generated $80,391 in purchasing for participating local farms was brought to University of Kentucky's campus thanks to the Salad Bar Program. This program is projected to continually expand with UK Dining, its operator Aramark, and through other farm-to-institution markets (Brislen et al., 2019).

However, suboptimal winter conditions create a challenge for growers over winter months to achieve continual harvest to meet market demands (Hodge et al., 2018). Local climate data have been utilized broadly to track crop growth and mitigate crop stress in a wide variety of agronomic and horticultural crops (Khanal et al., 2018). Growing degree-days (GDD), a unit of physiological time, has been effectively used to improve crop growth and harvest date predictions, though information is dependent on microclimate, crop, and variety (Andrews & Noordijk, 2018). Such tools may be particularly important when crops are grown outside of the primary growing season when calendar days-to-maturity are not accurate predictors of crop development and maturation due to limiting environmental factors (e.g. heat and/or light; Wiediger and Weidiger, 2003).

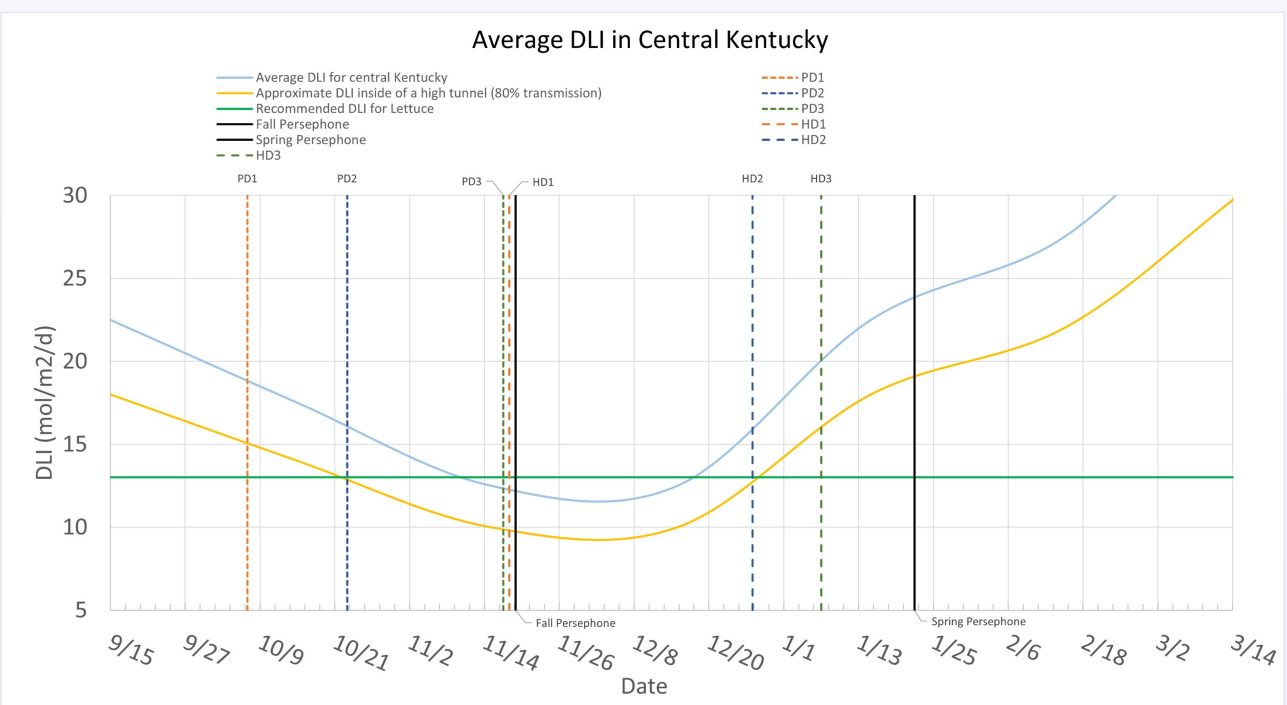

Figure 1. Graph of Average DLI Values (Faust & Logan, 2018) and the approximate DLI value experienced inside of a high tunnel with two layers of plastic (80% transmission). Also marked are planting dates (PD) and harvest dates (HD) from the three lettuce planting successions from this study's first season, and the Persephone Period for Central Kentucky.

Over winter, low light conditions can limit crop growth even if high tunnel air temperatures are adequate (Baumbauer et al., 2019). Daily light integral (DLI) is a way of quantifying the total photosynthetic photon flux a crop experiences over a 24-hour period, described in units of $mol{\cdot}m^{-2}{\cdot}d^{-1}$. Lettuce requires a minimum DLI of 12-14 $mol{\cdot}m^{-2}{\cdot}d^{-1}$ (Runkle, 2011). Central Kentucky in December and January experiences DLI values as low as 10 $mol{\cdot}m^{-2}{\cdot}d^{-1}$ (Faust & Logan, 2018). Figure 1 illustrates how average DLI values dip below the recommended DLI (averaged to 13 $mol{\cdot}m^{-2}{\cdot}d^{-1}$) for lettuce growth. Minimum DLI for spinach growth is lower, at 8 $mol{\cdot}m^{-2}{\cdot}d^{-1}$ (Baumbauer et al., 2019).

Using DLI as a standard for light that contributes to plant growth is becoming increasingly popular in the horticulture profession thanks to the availability of affordable sensors and educational materials about DLI (Faust & Logan, 2018). Alternatively, many small-scale farmers plan their winter crop successions in anticipation of when daylight hours are less than 10 hours per day, called the "Persephone Period," at which time it is claimed that plant growth "essentially stops" ("Winter Growing", 2018). For Central Kentucky, the "Persephone Period" is approximately from November 19th-January 21st (as reported on TimeandDate.com).

OBJECTIVES

The objectives of this study are: 1) to develop GDD-based models to effectively predict growth of select leafy green and root vegetable crops, and 2) identify time periods of poor model fit where additional environmental factors may need to be considered.

METHODS

Three crops utilized in the UK Salad Bar Program, a local food procurement effort by UK Dining, have been selected for this project. These include lettuce ('Salanova Red Sweet Crisp,' 'Salanova Green Sweet Crisp,' 'Salanova Red Incised,' and 'Salanova Green Incised'), spinach ('Corvair') and carrot ('Yaya') (Johnny's Selected Seeds, Waterville, ME). Data were collected from three planting successions at four sites: the University of Kentucky Horticulture Research Farm and three participating cooperator farms in central Kentucky (Fayette Co., Woodford Co., and Scott Co.) from Fall 2020-Spring 2021. Crops were planted in beds according to local farmer practice, with data collected from 11 marked plants located in the center rows of the bed. Planting date 1 (PD1) for spinach was planted in open field systems, while subsequent planting dates (PD2 and PD3) took place in season extension environments (i.e., in high tunnels and/or under row cover). Crop growth stage was collected via non-destructive sampling methods that document vegetative and root growth appropriate to the crop and market stage (e.g., leaf count and root diameter). Growth stage data were collected every 7-10 days at each site.

GDD were calculated using the simple average method with a horizontal cutoff, which assumes crop growth is halted or significantly slows or stops below a base growth temperature or above an upper threshold temperature. GDD are calculated using the simple average method with a horizontal cutoff, described by the conditional equation:

$$\text{if } T_{max}<T_{high}, \text{ then } \frac{(Tmax+Tmin)}{2} - Tba_{se}; \text{ else } \frac{(Thigh+Tmin)}{2} - Tba_{se}$$

where T_{high} is the upper threshold temperature, T_{base} is the base temperature, T_{max} is the daily maximum temperature, and T_{min} is the daily minimum temperature ("About degree-days," 2016). T_{base} and T_{high} values were 4°C and 24 °C, respectively, as has been utilized previously in GDD studies for lettuce (Maynard & Hochmuth, 1997; Wien, 1997) and spinach (Drost, 2017). Temperature data were collected from each site using WatchDog A-Series Loggers (Model A125) with an external temperature probe to monitor soil temperature (Spectrum Technologies Inc., Aurora, IL) at 15-minute intervals. Data loggers were placed slightly above the plant canopy (18-24in), and soil temperatures probe was placed at 3in soil depth.

Preliminary GDD model predictions of the first season of data were evaluated using simple linear regression (Proc REG) in SAS (SAS Version 9.4; SAS Institute, Cary, NC).

PRELIMINARY RESULTS

Lettuce, All sites R^2 Values	All PD	PD1	PD2	PD3
All varieties	0.39	0.67	0.38	0.51
Red Incised	0.45	0.77	0.47	0.65
Green Incised	0.41	0.79	0.34	0.67
Red Sweet Crisp	0.43	0.79	0.43	0.68
Green Sweet Crisp	0.49	0.8	0.49	0.71
Red Varieties (RI+RC)	0.44	0.77	0.44	0.65
Green Varities (GI+GC)	0.41	0.71	0.4	0.53
Incised - Red and Green	0.42	0.77	0.41	0.5
Sweet Crisp - Red and Green	0.4	0.65	0.41	0.66

Table 1. R^2 values for the lettuce ('Salanova'), aggregated by site.

All varieties, R^2 Values				
Site	All PD	PD1	PD2	PD3
Horticulture Research Farm	0.5	0.65	0.64	0.59
Woodford County	0.52	0.73	0.75	0.68
Scott County	0.42	0.67	0.52	0.34

Table 2. R^2 values for all varieties of 'Salanova' lettuce, aggregated by site and planting date.

PRELIMINARY RESULTS (cont.)

For lettuce, R^2 values are generally higher at the earlier planting dates and lower at later planting dates (Table 1). However, this season's data shows that R^2 values for lettuce PD2 are lower than R^2 values for PD3. The variety 'Green Sweet Crisp' had the best fit for all planting dates. When analyzed by color, the red-leaved varieties have a higher R^2 value. Additionally, the 'Incised' varieties have a higher R^2 value than the 'Sweet Crisp' varieties (Table 1). Table 2 also demonstrates the decrease in R^2 values at later planting dates. The R^2 values for spinach were fairly consistent across planting dates and sites, with slightly improved fit at the latest planting date (PD3) (Table 3).

Spinach, R^2 Values	All PD	PD1	PD2	PD3
All Sites	0.72	0.85	0.84	0.86
Horticulture Research Farm	0.79	0.84	0.83	0.78
Woodford County	0.82		0.86	0.88
Fayette County	0.87	0.86	0.9	0.93

Table 3. R^2 values for spinach ('Corvair') by site and planting date.

Lettuce yields from earlier planting dates were greater than subsequent plantings, with 'Green Sweet Crisp' from PD1 as the highest yielding, and 'Red Sweet Crisp' from PD3 as the lowest yielding (Table 4).

Average Lettuce Yield (g)			
Lettuce, All sites	**PD1**	**PD2**	**PD3**
Average Days to Harvest	42	66	61
All varieties	72.7	50.1	34.1
Red Incised	50.8	33.5	26.8
Green Incised	61.3	45.2	33.2
Red Sweet Crisp	59.8	39.6	19.5
Green Sweet Crisp	119.1	82.0	57.0
Red Varieties (RI+RC)	110.6	73.1	46.3
Green Varities (GI+GC)	180.4	127.2	90.2
Incised - Red and Green	112.1	78.7	60.0
Sweet Crisp - Red and Green	178.9	121.7	76.5

Table 4. Lettuce yield by variety per planting date from all sites. Note, no statistical comparisons have been made at this time.

DISCUSSION

Preliminary GDD regression data indicate reasonable model fit (R^2 >0.67) during early planting dates, with poorer model fit at later planting dates. This suggests that crops are experiencing environmental limitations to growth besides temperature at the later planting dates, which is mostly likely a light limitation (Figure 1). However, the lower-than-expected PD2 for all lettuce varieties suggests that an additional factor besides light and temperature may be inhibiting growth, such as a water limitation, or the light limitation may be occurring sooner than anticipated due to the regional low DLI.

It is of note that the DLI periods below suggested lettuce DLI minima values do not correlate directly with day length and are not symmetrical around the winter solstice. Further, DLI data indicate that light availability for cool season leafy green production may occur earlier in the year and end sooner than traditional farmer knowledge may imply. Specifically, limitation in plant-available light is commonly thought to occur during the "Persephone Period," a period of short day-length occurring symmetrically around the winter solstice. This merits further research and data exploration to determine when crop growth is slowing due to light limitation, as predicted by poor model fit to GDD within each planting date. Further, additional research is needed to determine the efficacy and cost effectiveness of supplemental heat and/or light at times informed by these preliminary data.

DISCUSSION (cont.)

Additional analyses and discussion with participating farmers are needed to explore differences in R^2 values between sites. For example, PD3 at the Scott County site demonstrated a very low R^2 value (0.34) compared to the other sites at the same planting date (0.59-0.68). This may be due to light limitation caused by localized shading of the tunnel structure, and could be informed by additional light (PAR) readings at each site.

Yield data were collected primarily for participating producers to equate crop growth stage to harvest weight. Additional yield data collected at multiple crop growth stages may improve the utility of future decision tools developed from crop growth models, as producers may harvest crops early or at variable market stages, depending on market preference and demand.

Relatively high R^2 values for the spinach at all planting dates may indicate that spinach is not light limited during winter in Central Kentucky, which is supported by literature that indicates DLI minima for spinach may be as low as 8 $mol{\cdot}m^{-2}{\cdot}d^{-1}$ (Baumbauer et al., 2019). Future research utilizing supplemental heat in spinach may be particularly cost effective and of interest to producers.

CONCLUSIONS AND NEXT STEPS

During this first season of data collection and piloting of methods, simple GDD models show promise as reasonable predictors of lettuce crop growth at early planting dates, and for spinach throughout the fall. Climate and crop growth data indicate that limitations in plant-available light do not align directly with traditional notions of these periods (i.e., "Persephone Period"). A minimum of two additional seasons of data, as well as exploring higher-resolution methods of calculating GDD and exploring the relationship between temperature, DLI, and photoperiod, will improve model fit and guide additional research efforts.

REFERENCES

About degree-days. (2016). Agriculture and Natural Resources, University of California. Retrieved from http://ipm.ucanr.edu/WEATHER/ddconcepts.html

Andrews, Nick & Noordijk, Heidi. (2016). Croptime: Scheduling Vegetables with Degree-Day Models. Retrieved from https://extension.oregonstate.edu/crop-production/vegetables/croptime-scheduling-vegetables-degree-day-models

Baumbauer, D.A., Schmidt, C.B. & Burgess, M.H. (2019). Leaf Lettuce Yield is More Sensitive to Low Daily Light Integral than Kale and Spinach. *HortScience 54*(12):2159-2162. https://doi.org/10.21273/HORTSCI14288-19

Brislen, L., Breen, J.M., and Maynard, L. (2019). UK Dining Sourcing Report: Fiscal Year 2019. [PDF File]. The Food Connection https://foodconnection.ca.uky.edu/files/anaylsis_of_uk_dining_food_sources_2019_final.pdf

Drost D., Ernst T., & Black B. (2017). Soil heating and secondary plant covers influence growth and yield of winter high tunnel spinach. *HortScience 52*(9): 1251-1258.

Faust, J.E. & Logan, J. (2018). Daily Light Integral: A Research Review and High-resolution Maps of the United States. *HortScience 53*(9):1250-1257. https://doi.org/10.21273/HORTSCI13144-18

Hodge F., et al. (2018). Yield of leafy greens and microclimate in deep winter greenhouse production in Minnesota. *Sustainability 11*(1): 28-39.

Khanal, S. Fulton, J., Shah, A., Shearer, S., and Hawkins, E. (2018.) Free Online Data Tools for the Agricultural Community. Ohioline.osu.edu. https://ohioline.osu.edu/factsheet/fabe-55204

Maynard, D. N., and G.J. Hochmuth. (1997). *Handbook for Vegetable Growers* (4th ed.). USA: John Wiley & Sons, Inc.

Runkle, E. (2011). Lighting Greenhouse Vegetables. https://gpnmag.com/article/lighting-greenhouse-vegetables/

Wiediger, P., and A. Wiediger. 2003. *Walking to Spring.* Au Naturel Farm, Smiths Grove, KY.

Wien, H.C. (1997). Lettuce. In H.C. Wien (Ed.), *The Physiology of Vegetable Crops* (pp. 479-509). Cambridge, UK: Cab International.

Winter Growing: A Guide to Winter Harvest Crops & Overwintering for Spring Harvest. (2018). [PDF File]. https://JohnnySeeds.com/WinterGrowing

ACKNOWLEDGEMENTS

Big thank you to Dr. Krista Jacobsen for her teaching and guidance in my first semester. This work was funded by the Kentucky Department of Agriculture Specialty Crops Block Grant Program and the Food Connection at the University of Kentucky. I'd like to thank the participating farmers for their participation, support, and expertise. Finally, thanks goes out to faculty and staff at the University of Kentucky Horticulture Research Farm and the UK CSA for their technical support.