Lifting Dates, Chilling Hours, and Storage Duration on Slash Pine Seedling Root Growth Potential, Growth, and Survival

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Introduction

- Lifting usually occurs between late November and late February, the optimum time when seedlings are dormant.
- These seedlings are packed in boxes, bags, or bundles and placed in cold storage for a 2- to 3-week period before being shipped.
- Seedling storage avoids issues of mold and decay, which can decrease seedling survival after outplanting
- Weather conditions, however, are not always favorable and may delay outplanting, thus requiring longer storage durations than recommended.
- With fluctuating freezing and above-normal temperatures occurring more often across the Southern U.S. during the winter months of December, January, and February, there are concerns regarding optimum lifting time, seedling storability, and seedling growth and survival after outplanting

Introduction

- Environmental conditions during seedling growth in the nursery impacts seedling quality and physiological readiness for storage and outplanting
- Seedling quality can be defined as a seedling that can survive periods of environmental stress and produce vigorous growth following outplanting
- Seedlings must be physiologically ready to grow. Photoperiod and environmental cues during the growing season within the nursery are fundamental to this physiological readiness
- Seedling dormancy, cold hardiness, and the accumulation of carbohydrate reserves are the main physiological processes that ensure seedlings are physiologically ready to withstand the stresses of lifting, handling, and planting such that optimal root and shoot growth can occur after outplanting

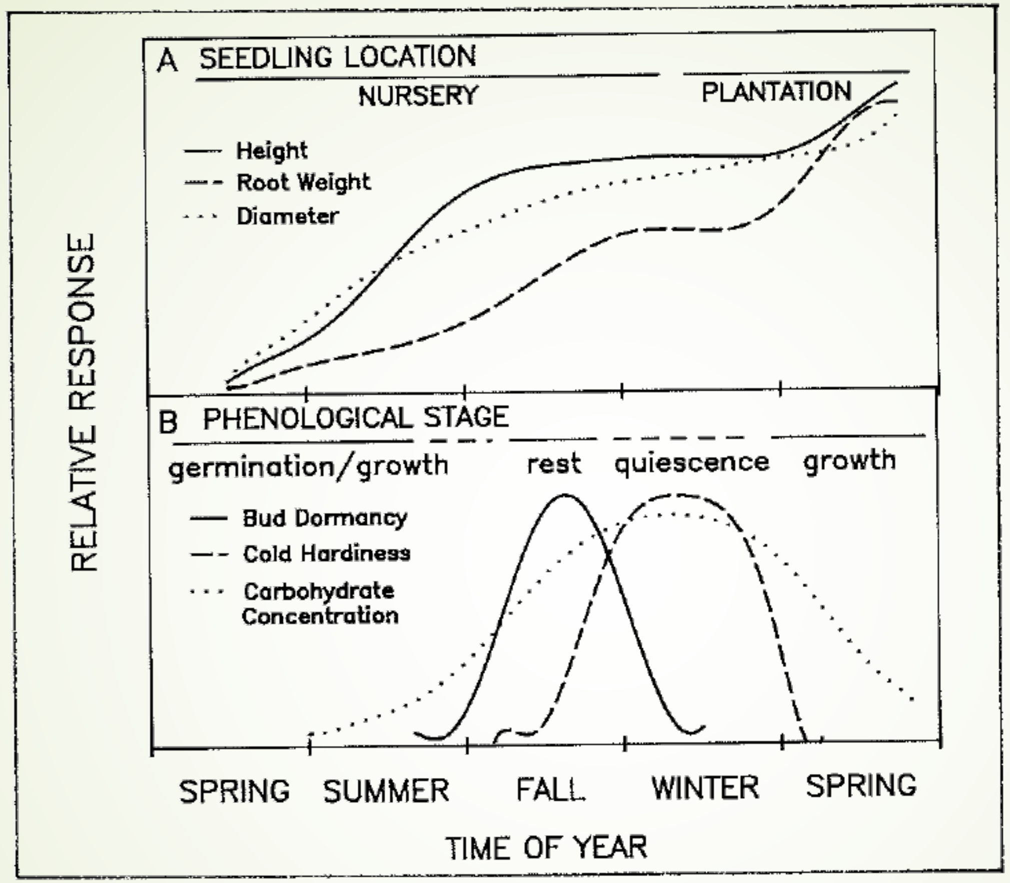


Figure 8.1. Idealized changes in seedling morphology (A) and physiology (B) over time.

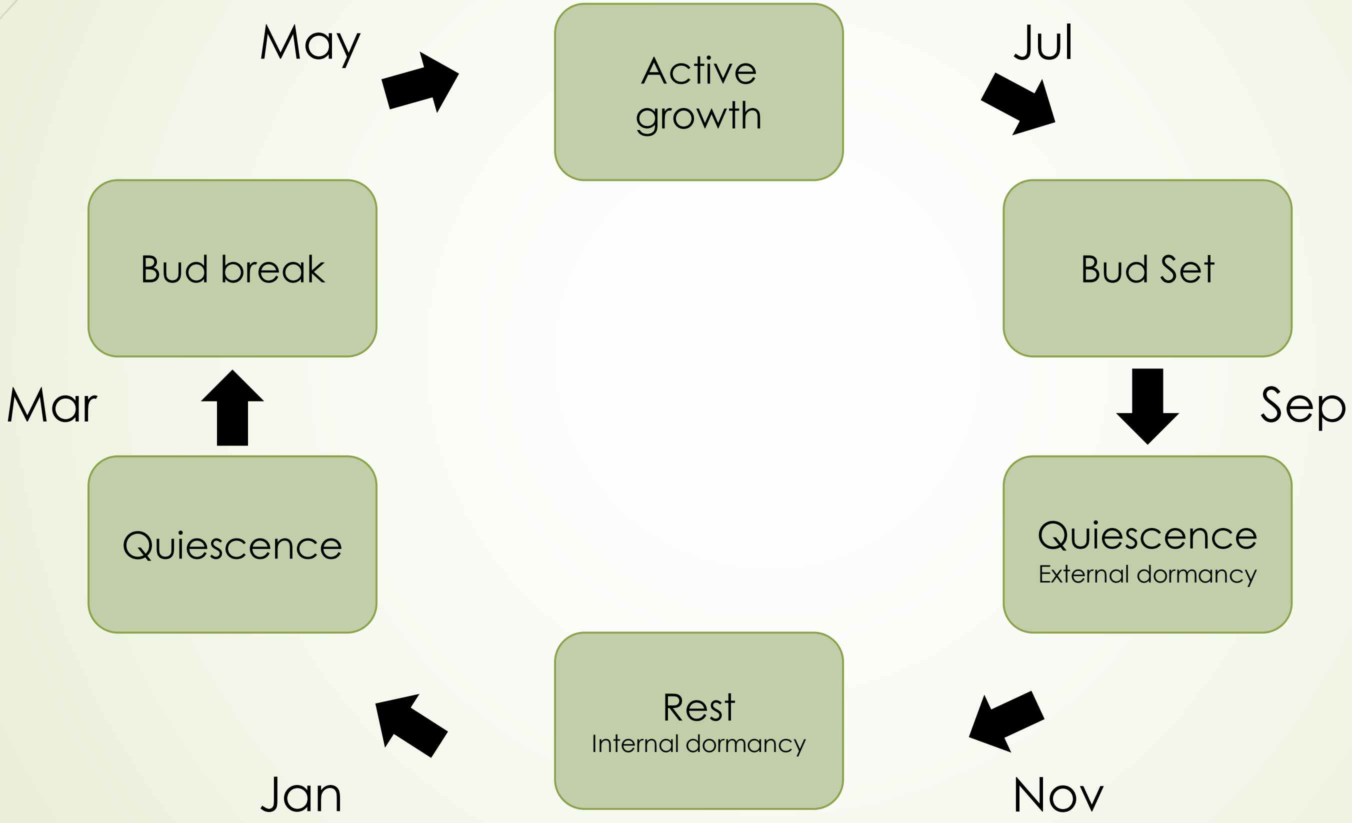
Bud dormancy commences in mid-fall (Oct-Nov) and the development of cold hardiness in all seedling tissues follows in early winter (Dec -Jan)

Johnson and Cline (1991). *In* Duryea and Dougherty (editors) Forest regeneration manual

Cold hardiness and dormancy

- Physiologically, bud dormancy can arise whenever stressful environmental conditions occur, even during active growth. For example, drought, temperature extremes, or nutrition limitations can cause bud dormancy.
- Bud dormancy during the active growth stage is, however, reversible with the removal of the environmental stress.
- Typically, active growth of conifer seedlings slows in summer and bud formation occurs with the initiation of quiescence (ectodormancy). If favorable conditions occur for seedling growth, ectodormancy is reversible.
- Beginning late fall (October/ November), true internal dormancy (endodormancy) starts and continues into December. During endodormancy, seedlings will not resume growth even when favorable conditions for growth are present. Growth resumes after seedlings experience a certain period of low temperatures (chilling requirement). Once the chilling requirement is met, the seedling re-enters ectodormancy and will resume growth if favorable conditions (primarily warmer temperatures) are present
- For Southern pine species, little is known about the dormancy cycle and its relation to photoperiod and temperature. Both nutrition and water availability can influence bud development timing

Typical phenological cycle



Cold hardiness and dormancy

- Cold hardiness develops with physiological changes throughout all seedling tissues following the suspension of rapid cell expansion.
- For Southern pine species, cold temperature acclimation in response to decreasing air temperatures is referred to as hardening initiating. Thus, cold hardiness initiates after bud dormancy initiation.
- Although the two are often referred to synonymously, they are completely separate processes (Haase 2011)The two processes normally occur sequentially

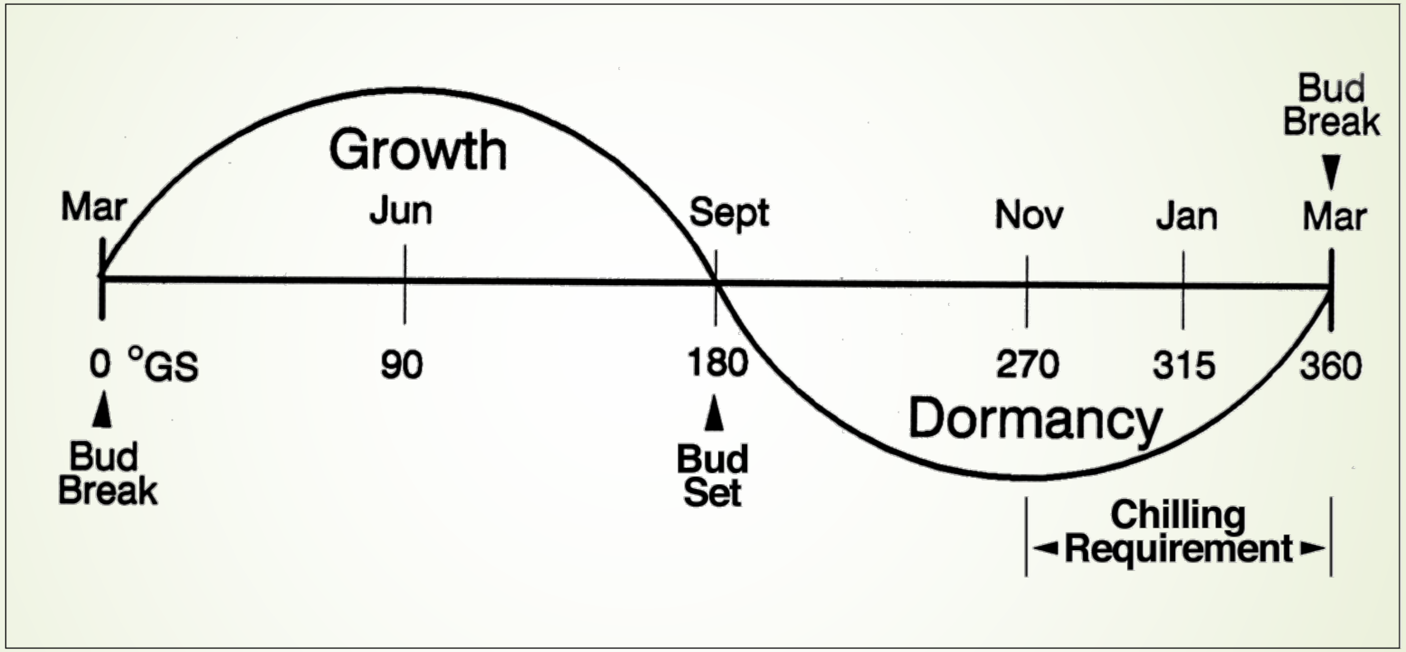


Figure 1. The shoots of all perennial plants, including forest and conservation nursery stock, undergo a seasonal cycle of shoot growth and dormancy. Note that peak dormancy occurs in late fall instead of mid-winter as is popularly believed. Bud dormancy is released by cumulative exposure to cold temperatures - the chilling requirement (modified from 2).

Ritchie and Landis -Forest Nursery Notes 2004

Chilling hours and seedling storage

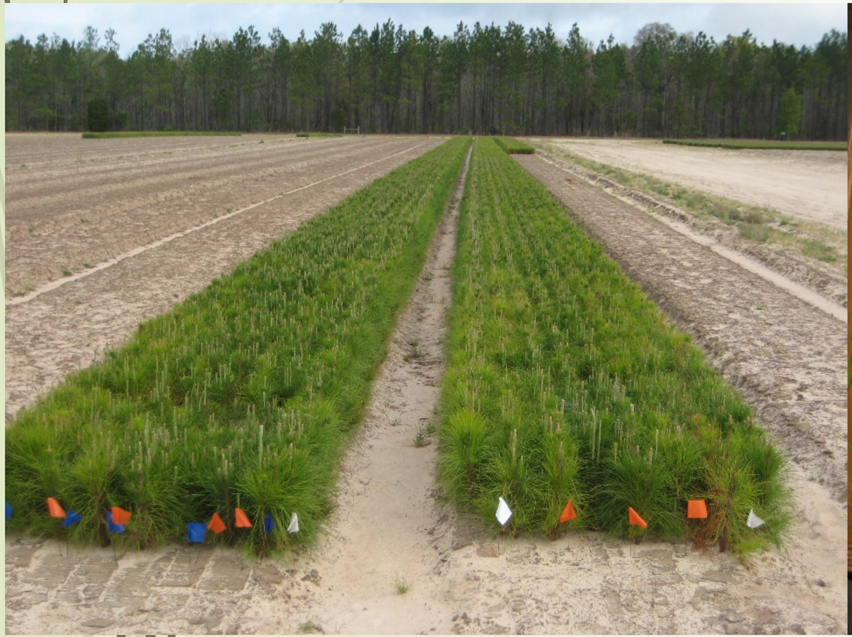
- Seedling chilling hours are quantified based on the cumulative number of hours of exposure to a specified range of cold temperatures.
- The accepted temperature range to define a chilling hour is often species and nursery dependent.
- In the Southeastern U.S., chilling hours are usually quantified in the range of 32 to 46 °F (0 to 8 °C), and temperatures below 32°F do not count.
- Using this preferred method of chilling hour calculation, nurseries target 200 to 400 chilling hours for loblolly pine (*Pinus taeda* L.) to overcome rest (internal dormancy) depending on geographic origin.
- For the Southeastern U.S., this chilling hour target is usually met in early to mid-December after which point seedlings can be lifted for long- or short-term storage.

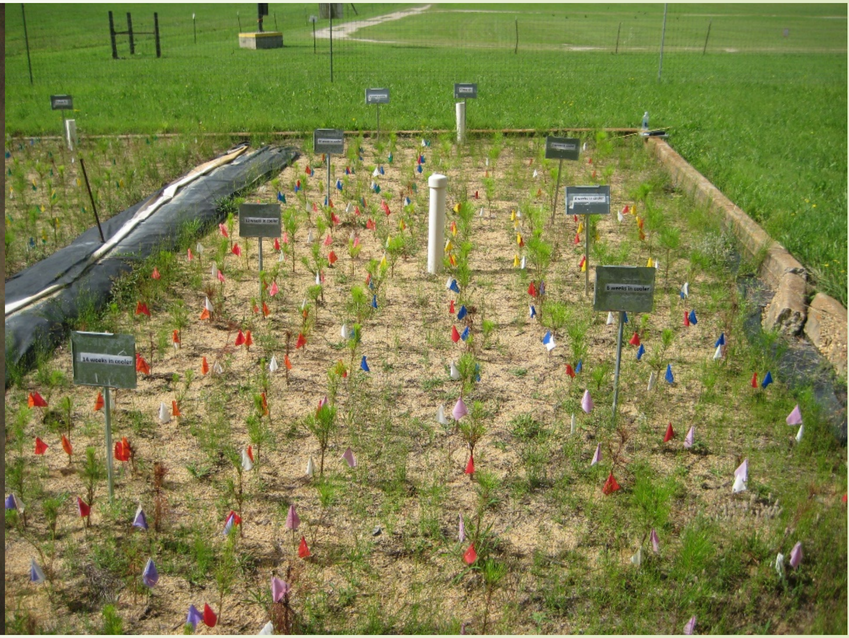
Chilling hours and seedling storage

- Although chilling hours is known to be beneficial to pine seedlings, the impact of chilling hours on seedling storability and their subsequent growth is poorly understood, as evidenced by several popularly held myths

Materials and methods

- For this study, a single seedlot (genotype) of slash pine (*Pinus elliottii* Engelm.) was used over 3 seedling production and lifting seasons (2016 – 2017; 2017 -2018; and 2018 – 2019)





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Materials and methods

- For each lifting season, 1000 seedlings (equivalent to a full box of seedlings) were hand lifted from the bareroot nursery bed at the start of the study period (January). Every 2 weeks thereafter, for a total of 6 lift dates ending in late-April/early May each year ($Time_0$, $Time_1$, $Time_2$, $Time_3$, $Time_4$, $Time_5$).

Table 2: Sample groups of seedlings (indicated by +) each year for the different combinations of lifting and cooler storage periods.

Storage duration (weeks)	2017						2018						2019			
	Lift date						Lift date						Lift date			
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3
0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
6	X	X	X	X	X		X	X	X	X			X	X	X	X
8	X	X	X	X			X	X	X				X	X	X	
10	X	X	X				X	X					X	X		
12	X	X					X						X			
14	X															

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Materials and methods

- At each lift date, 15 seedlings were randomly selected for measurement and outplanting (storage duration = 0); the rest were placed into cooler storage (33 to 37 °F [0.6 to 2.8 °C]) in standard shipping boxes.
- Over a 14-week period, 15 seedlings from each lift date were randomly removed from the cooler, measured, and outplanted for a maximum of eight storage durations.
- There were a total of 82 lift date/storage duration sample groups for a total of 1,230 seedlings (820 outplanted) over the study's three seasons.

Results

Table 1: Chilling hours calculated for each seedling-lifting period over three lifting seasons.

YEAR	Number of chilling hours at time of lifting					
	$Time_0$	$Time_1$	$Time_2$	$Time_3$	$Time_4$	$Time_5$
2017	-302	-426	-428	-636	-820	-1016
2018	97	142	121	-103	-91	-152
2019	118	135	-6	-67	-142	-262

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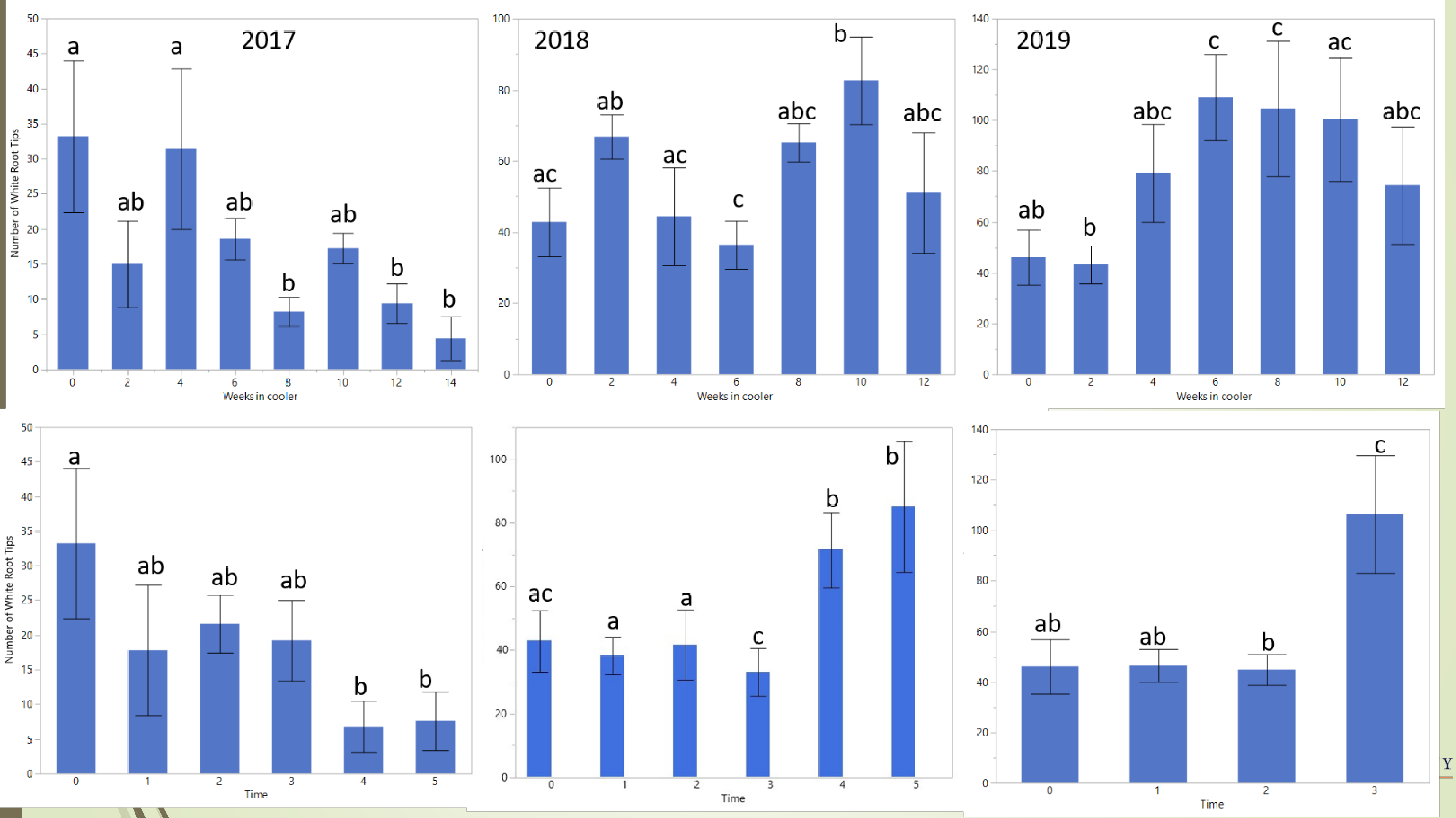
2017
2018
2019
Number of White Root Tips
Weeks in cooler
Time
a ab a ab b ab b b
ac ab ac c abc b abc
ab b abc c c ac abc
a ab ab ab b b
ac a a c b b
ab ab b c

Y

Storage duration (weeks)	Shoot Mass (g)						Root Mass (g)					
	Year 2017											
	Lift date						Lift date					
	0	1	2	3	4	5	0	1	2	3	4	5
0	36.32	26.31	.	36.92	10.77	9.66	8.83	8.15	.	10.27	2.38	3.07
2	26.42	22.65	22.72	28.35	10.59	4.65	8.34	7.63	7.45	9.37	2.32	0.36
4	15.48	20.12	17.66	19.05	10.65	5.07	4.64	7.34	5.60	6.49	2.42	1.01
6	13.85	19.82	30.01	21.02	12.52	.	5.31	6.70	12.64	6.40	3.36	.
8	12.45	32.33	13.14	13.85	.	.	3.24	12.17	5.31	3.23	.	.
10	16.98	19.34	7.37	.	.	.	4.01	6.91	2.62	.	.	.
12	8.70	12.95	.	.	.	.	1.69	6.10	.	.	.	.
14	7.93	.	.	.	.	.	2.26	.	.	.	.	.

Storage duration (weeks)	Year 2018											
	Lift date						Lift date					
	0	1	2	3	4	5	0	1	2	3	4	5
0	6.35	10.80	9.54	3.92	5.85	6.86	3.63	4.72	5.06	1.92	2.89	2.85
2	6.47	13.98	9.22	6.25	5.20	7.96	4.12	7.68	5.67	3.46	2.32	3.22
4	8.50	9.43	10.49	7.13	4.83	.	4.88	5.18	6.45	4.27	1.87	.
6	4.61	9.53	7.50	5.52	.	.	3.09	5.51	5.31	2.95	.	.
8	7.01	5.08	8.00	.	.	.	3.82	4.71	4.19	.	.	.
10	5.36	7.66	.	.	.	.	3.25	3.86	.	.	.	.
12	5.79	.	.	.	.	.	4.96	.	.	.	.	.

Storage duration (weeks)	Year 2019											
	Lift date						Lift date					
	0	1	2	3	4	5	0	1	2	3	4	5
0	7.51	7.83	6.99	5.94	.	.	2.35	2.36	1.87	1.86	.	.
2	3.65	6.67	5.01	5.33	.	.	1.31	1.52	1.65	1.57	.	.
4	4.84	7.41	3.79	3.22	.	.	1.56	1.92	0.64	1.02	.	.
6	4.35	3.69	2.31	.	.	.	1.27	1.11	0.9	.	.	.
8	2.08	2.93	1.82	.	.	.	0.93	0.85	0.91	.	.	.
10	3.08	7.34	.	.	.	.	1.02	1.98	.	.	.	.
12	2.7	.	.	.	.	.	1.22	.	.	.	.	.

- After one growing season, both shoot and root mass decreased with both increasing storage duration and later lift dates.
- Roots and shoots compete within the plant for carbohydrates. Lifting later in the growing season usually means higher temperatures which stimulate bud elongation and reduce root growth.
- The ability for seedlings to grow roots shortly after planting is positively correlated to improved seeding survival after outplanting

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Storage duration (weeks)	shoot: root						Root weight ratio					
	Year 2017											
	Lift date						Lift date					
	0	1	2	3	4	5	0	1	2	3	4	5
0	4.1	3.2	.	3.6	4.5	3.1	19.6	23.7	.	21.8	18.1	24.1
2	3.2	3.0	3.0	3.0	4.6	12.9	24.0	25.2	24.7	24.8	18.0	7.2
4	3.3	2.7	3.2	2.9	4.4	5.0	23.1	26.7	24.1	25.4	18.5	16.6
6	2.6	3.0	2.4	3.3	3.7	.	27.7	25.3	29.6	23.3	21.2	.
8	3.8	2.7	2.5	4.3	.	.	20.7	27.4	28.8	18.9	.	.
10	4.2	2.8	2.8	.	.	.	19.1	26.3	26.2	.	.	.
12	5.1	2.1	.	.	.	.	16.3	32.0	.	.	.	.
14	3.5	.	.	.	.	.	22.2	.	.	.	.	.

Storage duration (weeks)	Year 2018											
	Lift date						Lift date					
	0	1	2	3	4	5	0	1	2	3	4	5
0	1.7	2.3	1.9	2.0	2.0	2.4	36.37	30.41	34.66	32.85	33.07	29.35
2	1.6	1.8	1.6	1.8	2.2	2.5	38.90	35.46	38.08	35.63	30.85	28.81
4	1.7	1.8	1.6	1.7	2.6	.	36.47	35.46	38.08	37.46	27.91	.
6	1.5	1.7	1.4	1.9	.	.	40.13	36.64	41.45	34.83	.	.
8	1.8	1.1	1.9	.	.	.	35.27	48.11	34.37	.	.	.
10	1.6	2.0	.	.	.	.	37.75	33.51	.	.	.	.
12	1.2	.	.	.	.	.	46.14	.	.	.	.	.

Storage duration (weeks)	Year 2019											
	Lift date						Lift date					
	0	1	2	3	4	5	0	1	2	3	4	5
0	3.2	3.3	3.7	3.2	.	.	23.8	23.2	21.1	23.8	.	.
2	2.8	4.4	3.0	3.4	.	.	26.4	18.6	24.8	22.8	.	.
4	3.1	3.9	5.9	3.2	.	.	24.4	20.6	14.4	24.1	.	.
6	3.4	3.3	2.6	.	.	.	22.6	23.1	28.0	.	.	.
8	2.2	3.4	2.0	.	.	.	30.9	22.5	33.3	.	.	.
10	3.0	3.7	.	.	.	.	24.9	21.2	.	.	.	.
12	2.2	.	.	.	.	.	31.1	.	.	.	.	.

- Shoot: Root (S:R) ratios for seedlings at the end of the growing season were greatest for the 2017 growing season.
- Shoot: root ratios are commonly used as measurement of drought avoidance potential. For example, if the ratio is unbalanced there can be too many transpiring shoot tissues compared to the moisture absorbing root tissues, hence impacting drought tolerance
- >3 indicating the likely reason for the resulting lower seedling survival for seedlings lifted later in the 2017 growing season .
- When it comes to seedlings, survival is negatively correlated with S:R ratios but positively correlated with that of the RWR.
- Root weight ratios correlate well with seedling survival, greater root system size indicated that seedlings have an increase surface area to uptake water and essential nutrients to sustain shoots and thus enhancing the ability to overcome both water and planting stress.

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Storage duration (weeks)	RCD growth (mm)						Height growth (cm)						Survival (%)					
	Year 2017																	
	Lift date						Lift date						Lift date					
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
0	6.09	5.57	.	6.68	1.84	1.61	12.5	15.0	.	21.5	3.2	5.8	90	70	0	80	60	50
2	4.85	3.34	3.07	4.04	1.91	0.00	13.2	11.9	9.5	17.3	5.8	5.4	100	80	70	100	70	10
4	1.98	3.42	3.02	3.34	1.92	0.19	8.9	13.5	11.5	13.2	5.8	2.4	80	100	90	100	60	30
6	1.90	2.89	4.49	2.92	0.76	.	4.3	12.2	13.0	10.3	8.5	.	70	100	100	90	80	.
8	1.14	4.42	1.52	2.04	.	.	12.0	14.9	6.7	8.1	.	.	90	100	100	100	.	.
10	2.24	3.04	0.82	.	.	.	9.9	5.9	3.3	.	.	.	90	40	100	.	.	.
12	0.61	2.75	.	.	.	.	3.5	5.7	.	.	.	.	60	90	.	.	.	.
14	0.62	.	.	.	.	.	6.5	.	.	.	.	.	60	.	.	.	.	.

Storage duration (weeks)	Year 2018																	
	Lift date						Lift date						Lift date					
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
0	0.57	0.29	0.28	0.00	0.00	0.00	0.6	5.6	2.6	0.0	0.0	0.0	100	90	100	20	90	100
2	0.16	1.38	0.32	0.14	0.00	0.00	2.0	6.4	1.7	0.5	0.0	1.7	100	100	100	80	70	100
4	0.78	0.44	0.43	0.00	0.00	.	4.9	0.5	4.5	0.0	0.4	.	100	90	90	80	60	.
6	0.00	0.22	0.00	0.00	.	.	0.0	4.8	1.3	0.0	.	.	70	100	30	60	.	.
8	0.00	0.00	0.01	.	.	.	4.0	0.2	2.4	.	.	.	70	30	60	.	.	.
10	0.00	0.00	.	.	.	.	0.0	1.9	.	.	.	.	80	100	.	.	.	.
12	0.00	.	.	.	.	.	0.9	.	.	.	.	.	100	.	.	.	.	.

Storage duration (weeks)	Year 2019																	
	Lift date						Lift date						Lift date					
	0	1	2	3	4	5	0	1	2	3	4	5	0	1	2	3	4	5
0	0.68	0.61	0.08	0.00	.	.	2.8	5.1	0.0	0.0	.	.	100	100	90	80	.	.
2	0.00	0.01	0.00	0.00	.	.	2.6	1.3	0.0	0.0	.	.	100	100	80	100	.	.
4	0.00	0.00	0.00	0.00	.	.	1.9	5.6	0.0	0.0	.	.	100	100	40	90	.	.
6	0.00	0.00	0.00	0.00	.	.	1.0	0.8	0.0	0.0	.	.	100	100	40	0	.	.
8	0.00	0.00	0.00	.	.	.	0.8	0.3	0.0	.	.	.	100	80	70	.	.	.
10	0.00	0.07	.	.	.	.	0.0	2.2	.	.	.	.	100	100	.	.	.	.
12	0.00	.	.	.	.	.	0.0	.	.	.	.	.	100	.	.	.	.	.

- root growth was affected by the level of bud ectodormancy. For example, in 2017, seedlings were not ectodormant and actively growing when outplanted, seedlings planted having no cold storage (0 weeks in cooler) were thus larger in both RCD and height than those planted 12 weeks later as they had more time to grow.
- Enhanced bud break due to increased chilling hours resulted in better growth as seen when comparing the increase in growth in 2018 and 2019 growing season. For 2018 RCD and height $Time_1 > Time_2 > Time_0$ with seedlings having achieved higher chilling hours prior to being lifted were larger at the end of the season
- The ability for seedlings to increase chilling hours before being outplanted results in improved survival and growth than those with fewer chilling hours.

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Conclusion

- Chilling hours are not required for successful storage of seedlings with the success of seedling storage being species and genotype dependent.
- Improved survival once outplanted was partly related to the level of seedling bud ectodormancy impacting root growth.
- The growth and survival of seedlings once outplanted is, however, strongly affected by planting and growing conditions