SUPPLEMENTARY MATERIAL

South DB, Nadel RL (2020) Irrigation in pine nurseries. Reforesta 10: 39-82

Note: 1000 mm of irrigation is equivalent to 1000 kg of water per m^{-2}.

Table A1. **1937** ***Pinus echinata***. Total irrigation and estimated rainfall at the USFS Ozark Nursery at the Ozark National Forest, Russellville, Arkansas (35.28°N, 93.13°W). Seed (173 kg) were sown on 240 beds on March 2-18, 1937 (Erambert 1938). Total area irrigated not reported but the final average stocking was **228** seedlings m^{-2}. If 2.5 million seedlings were produced, then 1.1 ha of seedbed surface was irrigated which might equate to 1.7 ha of irrigated area. Average height of 1-0 seedlings ranged from 15 to 35 cm and root-collar diameter averaged 6.3 mm. If 2.8 million kg of water was used to produce 2.5 million seedlings, then 1.12 kg of irrigation was applied per seedling. Due to irrigation of non-seedbed areas, this value is 53% greater than the kg $seedling^{-1}$ ratio of 0.73. This ratio was determined by dividing **167** kg of irrigation water by **228** seedlings.

Month	Irrigations	$Cycle^{-1}$	Total irrigation	Estimated rainfall	Estimated irrigation
	#	kg	kg	mm	mm
April	9	27,946	251,513	83	15
May	8	54,211	433,685	129	26
June	8	61,880	495,040	107	29
July	10	67,146	671,459	83	39
August	13	75,648	983,419	79	58
Total	48		2,835,116	480	167
kg $seedling^{-1}$	0.73				

Table A2. **1938** ***Pinus banksiana***. Estimated irrigation and rainfall at the Hugo Sauer Nursery, Rhinelander, Wisconsin (45°38'N, 89°28'W). The soil had a silt-plus-clay content of 15%, a moisture equivalent of 8%, and a wilting coefficient of 4.3% (Stoeckler and Aamodt 1940). The mean of soil tensiometer measurements was wetter than -18 kPa. Approximately 1.9 million 2-0 seedlings ha^{-1}.

Month	Irrigations	$Cycle^{-1}$	Irrigation	Rainfall	Soil tension
	#	mm	mm	mm	kPa
May	1	4.4	4.4	129	>-12
June	3	6.1	18.3	109	>-12
July	2	2.0	4.0	72	>-20
August	2	4.5	9.1	118	>-18
Total	8		35.9	429	
kg $seedling^{-1}$	0.19				

Table A3. **1938 *Pinus resinosa*.** Estimated irrigation and at the Wyman Nursery, Manistique, Michigan (45°58'N, 86°14'W). Approximately 1.9 million 2-0 seedlings were produced on each ha (Stoeckler and Aamodt 1940). The soil had a silt-plus-clay content of 1.8%, a moisture equivalent of 3.8% and a wilting coefficient of 2.1%. Soil moisture typically wetter than -10 kPa.

Month	Irrigations	Cycle^{-1}	Irrigation	Rainfall	Soil tension
	#	mm	mm	mm	kPa
June	4	4.7	18.8	25.1	>-5
July	10	4.4	43.9	30.5	>-9
August	3	3.8	11.4	72.4	>-10
September	0	0	0	19.3	>-5
Total	17		74.1	147.3	
kg seedling^{-1}	0.39				

Table A4. **1953 *Pinus taeda***. Estimated irrigation and rainfall for the Auburn Nursery, Opelika, Alabama (32°34'N, 85°22'W). The 1-0 bareroot seedlings were grown in a soil with 75% sand and 17% silt (May et al. 1961). The soil moisture at field capacity averaged 9.7% with a bulk density of 1.6 g cm^{-3}. Total rainfall for 1953 was 1939 mm (597 mm above normal). Approximately 2.1 million seedlings ha^{-1} and seedlings were 19.3 cm tall at lifting.

Month	Irrigations	Cycle^{-1}	Irrigation	Rainfall	Soil moisture	Seedling height
	#	mm	mm	mm	%	cm
July	3	9.8	29.4	185	9.5	10.7
August	4	9.8	39.1	121	9.6	15.2
September	2	9.8	19.6	227	9.6	17.3
Total	9		88.1	533		
kg seedling^{-1}	0.42					

Table A5. **1959 *Pinus elliottii***. Estimated irrigation and rainfall for the Herty Nursery, Albany, Georgia (31°31'N, 84°13'W) (May et al. 1961). The 1-0 bareroot seedlings were grown in a soil with 89% sand and 9% silt. The soil had an average field capacity of 6.8% with a bulk density of 1.69 g cm^{-3}. Rainfall in 1959 totaled 143.3 cm (225 mm above normal). When soil moisture (SM) in the topsoil was at 6%, soil tension was at -30 kPa. Approximately 2.1 million seedlings ha^{-1}.

Month	Irrigations	Cycle^{-1}	Irrigation	Rainfall	Soil moisture	Seedling height
	#	mm	mm	mm	%	cm
June	3	7	20.9	66	7.7	-
July	3	7	20.9	175	7.2	14.5
August	4	7	28	57	7.8	21.6
September	0	0	0	104	6.9	26.4
Total	10		69.8	402		
kg seedling^{-1}	0.33					

Table A6. **1971 *Pinus radiata*.** Irrigation trial at the Benalla Nursery, Victoria, Australia (Minko 1976). Seeds were sown on 14 October 1971 at 300 m^{-2} and seedbed density after six months was 129 m^{-2} (no irrigation) and 155 m^{-2} (irrigation). Average root-collar diameter of seedlings in May was 5.8 mm.

Month	Irrigations	Cycle^{-1}	Irrigation	Rainfall	Days of rain	Height
	#	mm	mm	mm	#	cm
Nov (May)	0	0	0	46	3	2
Dec (June)	4	13.75	55	36	2	5
Jan (July)	4	31.25	125	32	2	11
Feb (Aug)	3	31.67	95	59	2	19
Mar (Sept)	3	23.67	71	12	1	30
Apr (Oct)	1	22	22	1	1	38
May (Nov)	0		0	?	?	45
Total	15		368	186		-
kg seedling^{-1}	2.4					

Table A7. **1978 *Pinus taeda.*** Irrigation at the Ashe Nursery, Brooklyn, Mississippi (31°01'N, 89°09'W). Seedlings were grown at a density of 226 m^{-2} (Martin 1978). One cycle (two hours) provides 12.7 mm of water. Sowing began on 21 April, and lifting began 11 December 1978.

Month	Irrigations	Irrigation	Rainfall
	#	mm	mm
April	7	89	105
May	6	76	200
June	7	89	115
July	4	51	133
Aug	6	76	119
Sep	8	102	49
Oct	6	76	13
Nov	4	51	316
Dec	0	0	31
Total	48	610	1081
kg seedling^{-1}	2.7		

Table A8. **1990 *Quercus robur***. Estimated irrigation (high rate) used for a bareroot nursery trial at the Horticulture Research International, East Malling, Kent, U.K. (51°17'N, 00°27'E), on a sandy loam soil (Hipps et al. 1997). Seeds were sown in November 1989 at 300 m^{-2}. Assuming 250 seedlings m^{-2}, the high rates of irrigation (3.08 kg seedling^{-1}) increased shoot dry mass by 0.76 g (65%) over the low rate (1.0 kg seedling^{-1}).

Month	Irrigations	Cycle^{-1}	Irrigation	Rainfall
	#	mm	mm	mm
May	31	6.7	207	4
June	30	3.3-6.7	160	55
July	31	3.3	200	8
Aug	31	3.3	104	26
Sep	30	3.3	100	35
Total	153		771	128
kg seedling^{-1}	3.1			

Table A9. **1996 *Pinus halepensis.*** Irrigation (23 September to 18 November) affects seedlings in a roofed greenhouse at the La Hunde Nursery at Valencia, Spain (39°05'N, 1°12'W) (Royo et al. 2001). Seeds were sown in mid-April in 200 cm^3 containers (387 m^{-2}). Midday needle water potentials (MPa) were recorded in October 1996 using a pressure chamber (just prior to rewatering). Seedlings were outplanted on 7 February 1997 and the number of dead seedlings (out of 60) were recorded on 10 October 1997. Unfortunately, each stress treatment was confounded with a different tree planter and this likely explains why early height growth was 1.4 cm greater when seedlings were planted with the root-collar 6 cm below the soil surface. For each column, means followed with the same letter were not statistically different (Tukey HSD, $\alpha = 0.05$). Insufficient information to calculate kg of water applied $seedling^{-1}$.

Trigger Volumetric water content	Irrigations	Height	RCD	Root mass	Total mass	Noon MPa	Greenhouse survival	Dead Seedlings October
%	#	cm	mm	g	g	MPa	%	#
10	≈3	12.3 c	2.07 b	0.41 b	1.17 a	-2.27 b	97	5
20	≈4	13.5 b	2.22 a	0.43 b	1.23 a	-1.73 a	100	4
32	≈6	13.1 bc	2.21 a	0.54 a	1.48 b	-1.69 a	100	7
46	≈8	15.0 a	2.30 a	0.61 a	1.54 b	-1.47 a	100	4

Table A10. **2001 *Picea glauca.*** Estimated irrigation and rainfall at a private nursery at Saint-Louis-de-Blandford, Canada (46°25'N, 72°00'W), (Lamhamedi et al. 2006). Seedlings were grown in IPL 25-350A containers (350 ml, square top opening) and a density of 183 cavities m^{-2}. Volumetric water content of 2-0 seedlings ranged from 25% to 45% and irrigation began on April 30. Seedlings were grown in an unheated polyethylene tunnel with no rainfall during the first year and were grown outside after April 2001.

Time period	Irrigations	$Cycle^{-1}$	Irrigation	Rainfall	Seedling height
	#	mm	mm	mm	cm
June 12 – 27	8	9.5	75.8	57.3	5.9
June 28 – July 11	4	5.9	23.6	47.6	9.4
July 12 – August 11	7	3.3	106.6	91.2	18.5
August 12 – Sept 10	5	3.6	17.9	147.7	22.9
Sept 11 – 27	6	3.6	21.6	65.5	29.7
Total	30		265.2	410.8	
$kg\ seedling^{-1}$	1.45				

Table A11. **2002** ***Picea glauca.*** Estimated irrigation at a private nursery at Saint-Louis-de-Blandford, Canada (46°25'N, 72°00'W) (Stowe et al. 2010). Seedlings (2-0) were grown in IPL 25-350A containers (350 ml, square top opening) and a density of 183 cavities m^{-2}. Irrigation was initiated on 30 April and each irrigation cycle applied 3.3 mm of water. A target volumetric water content of 55% was maintained by applying a total of 1.55 kg of irrigation per cavity. Seedlings were grown in an unheated polyethylene tunnel with no rainfall and seedlings were 35.7 cm tall on 24 October.

Month	Irrigations	Irrigation	Leachate
	#	mm	mm
May	9	30	6
June	12	40	8
July	21	70	14
Aug	24	80	16
Sep	15	50	10
Oct	4	13	1.2
Total	85	283	55.2
kg seedling^{-1}	1.55		

Table A12. **2013** ***Pinus tabuliformis.*** Estimated water use at the greenhouse of Beijing Forestry University near Jiufeng Mountain, Beijing, China (39°54'N, 116°28'E) (Shi et al. 2018). Seedlings were grown in 164 ml containers with 528 cells m^{-2} (Ray Leach Cone-tainers - SC10, Stuewe & Sons, Inc., Oregon, USA). Overhead irrigations were used during germination (applying about 100 g per cell) and this was followed with 50 subirrigation cycles. A subirrigation cycle (i.e. 17 ml of water per cell) was applied when volumetric water content dropped to 75%. Applying 17 ml per cell was equivalent to adding 8.9 mm of water. Leachate was reused in subsequent soaking cycles. Seedlings fertilized with a slow-release fertilizer before sowing (100 mg N $cell^{-1}$ or 528 kg N ha^{-1}). Seedlings were 9 cm tall at lifting (root-collar diameter 2.7 mm).

Month	**Irrigations**	**Irrigation**	**Leachate**
	#	mm	mm
March	-	52.8	-
April	3	26.9	4.0
May	5	44.9	6.7
June	7	62.8	9.4
July	10	89.8	13.4
August	13	116.7	17.4
September	7	62.8	9.4
October	3	26.9	4.0
November	2	18.0	2.7
Total	50	502	67
kg seedling^{-1}	0.73		

Table A13. **2014 *Pinus sylvestris.*** Estimated irrigation and rainfall at the Nedza Nursery at Katowice, Poland (50.168538°N, 18.317763°E). Seedlings were grown in HIKO V-120 containers at a density of 526 cavities m^{-2} (Durło et al. 2018). Seedlings were grown outside from 1 April 2014 to 30 October 2014. The maximum irrigation rate recorded was 16 mm per day.

Month	Estimated irrigations	Irrigation	Rainfall
	#	mm	mm
May	4	42.3	114.3
June	5	56.1	81.9
July	10	112	119.2
August	10	112.3	89
September	12	136.2	43.5
October	10	113	9.8
Total	51	571.9	457.7
kg seedling^{-1}	1.09		

Table A14. **2014 *Pinus occidentalis***. Estimated irrigation at a greenhouse at the Pitkin Forest Nursery in Moscow, Idaho (46°43032.000 N, 116°57020.400 W). The unfertilized seedlings were grown in a peat media and seed were sown on 12 June, 2014 (Hubbel et al. 2018). The container was a polybag (946 cm^3, 7.6 cm diameter, 19.1 cm height, ≈172 m^{-2}) were irrigated when the tray weight reached 80% of the weight at field capacity. In mid-December, seedlings were approximately 4 cm tall with a 1 mm RCD. Estimates are made for irrigation frequency (about every 8 to 10 days), amount applied per cycle (32 mm).

Month	**Estimated Irrigations**	**Estimated Irrigation**
	#	mm
June	2	64
July	4	128
August	4	128
September	3	96
October	2	64
Total	15	480
kg seedling^{-1}	2.8	

Table A15. **2017 *Pinus occidentalis.*** Effect of winter sprinkler irrigation on seedling morphology in a roofed greenhouse at Moscow, Idaho (46°43032.000 N, 116°57020.400 W). The peat moss-vermiculite mix was fertilized with a slow-release fertilizer (375 mg N cell^{-1} – 1,980 kg ha^{-1} of nitrogen) before sowing seed on 3 July 2017 (St John 2018). Seedlings were grown in 164 ml containers with 528 cells m^{-2} (Ray Leach Cone-tainers - SC10, Stuewe & Sons, Inc., Oregon, USA). Stress treatments were started on 6 September 2017 and ended on 16 December 2017. Seedlings were measured in December 2017. For each column, means followed with the same letter were not statistically different (Tukey HSD, $\alpha = 0.05$). Insufficient information to calculate kg of water applied seedling^{-1}.

Target Volumetric water content (g/g)	Irrigations	Irrigation	Height	RCD	Root volume	Turgor loss point	Survival in nursery
%	#	mm	cm	mm	ml	MPa	%
70	?	?	10.8	2.38	2.2	-1.05 a	98 a
30	?	?	7.8	1.64	1.0	-1.12 a	99 a
10	0	0	4.8	1.29	0.4	-1.22 a	88 b

Table A16. **2019 *Pinus palustris*.** Irrigation at the Claridge Nursery, Goldsboro, North Carolina (35°48'N, 78°07'W). Seedlings were grown in FT135 containers with 113 cc and a density of 581 m^{-2}. One hour of irrigation provides 19 mm of water and the timer is set for early morning (7 am) and mid-afternoon (2 pm) Sowing began on 13 May 2019 and `lifting began about 15 October and all seedlings were in storage by the end of December.

Month	Irrigation days	Cycles day^{-1}	Cycle length	Irrigation	Rainfall
	#	#	minutes	mm	mm
May	18	2	15	171	58.4
June	26	2	20	330	119.1
July	26	2	30	494	148.3
Aug	27	2	30	513	164.8
Sep	26	2	30	494	179.8
Oct	15	1	30	143	95.0
Nov	0	0		0	80.3
Dec	0	0		0	98.0
Total	138			2145	943.9
kg $seedling^{-1}$	3.7				

Table A17. **2019 *Pinus ponderosa*.** Irrigation at the CalForest Nursery, Etna, California (41°28'N, 122°49'W). Seedlings grown at a density of 430 m^{-2} in 130 cc volume cells (Styroblock 8). One hour of irrigation applies 24.3 mm of water. Seed were sown on April 28 and irrigation was stopped on 19 October. During the growing season, the trigger weight for irrigation increased from 5 kg in May to 7.26 kg in October. Assuming a Styroblock 8 trays at field capacity have an average weight of 6.66 kg, then a 75% trigger value was used in May (i.e. 5 kg/6.66 kg).

Month	Irrigations	Irrigation	Rainfall
	#	mm	mm
May	3	73	27
June	13	315	2
July	15	364	0
Aug	15	364	-
Sep	9	218	-
Oct	3	73	-
Total	58	1407	29
kg $seedling^{-1}$	2.65		

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