

Supplementary Information – Online Resource 1

Virtual pruning of 3D trees as a tool for managing shading effects in agroforestry systems

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Note: 'Online Resource 2' contains five animations of the pruned and unpruned tree structures (T2): N; p3d; p2d; p5w, and; p3w.

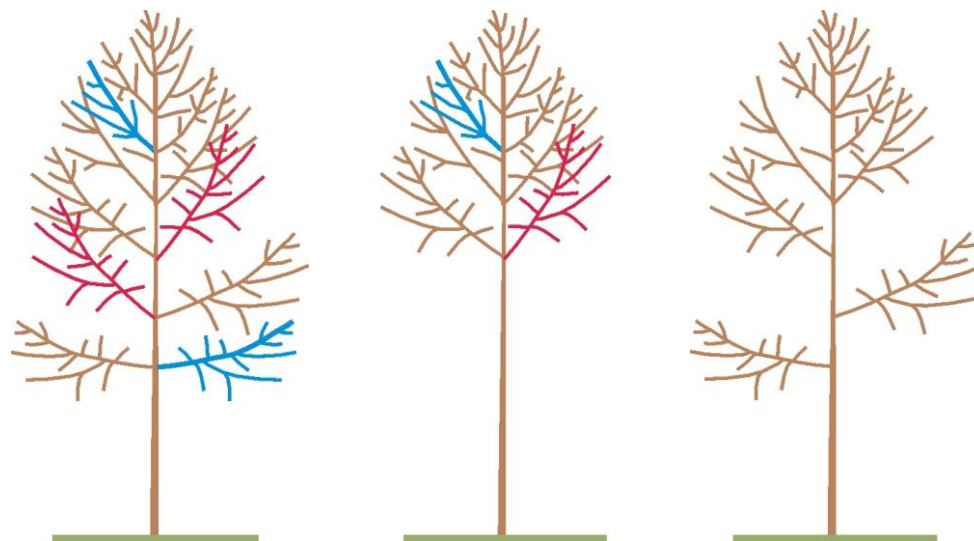


Fig. S1 Example of a tree (left) and its pruned structures after a conventional (middle) and selective (right) pruning intervention, where branches over a defined branch collar diameter (blue) or steeply-angled branches (red) are pruned



Fig. S2 Overview of the research site located in Breisach (Upper Rhine Valley), southwest Germany (48°4'24"N; 7°35'26"E, 182 m a.s.l.).

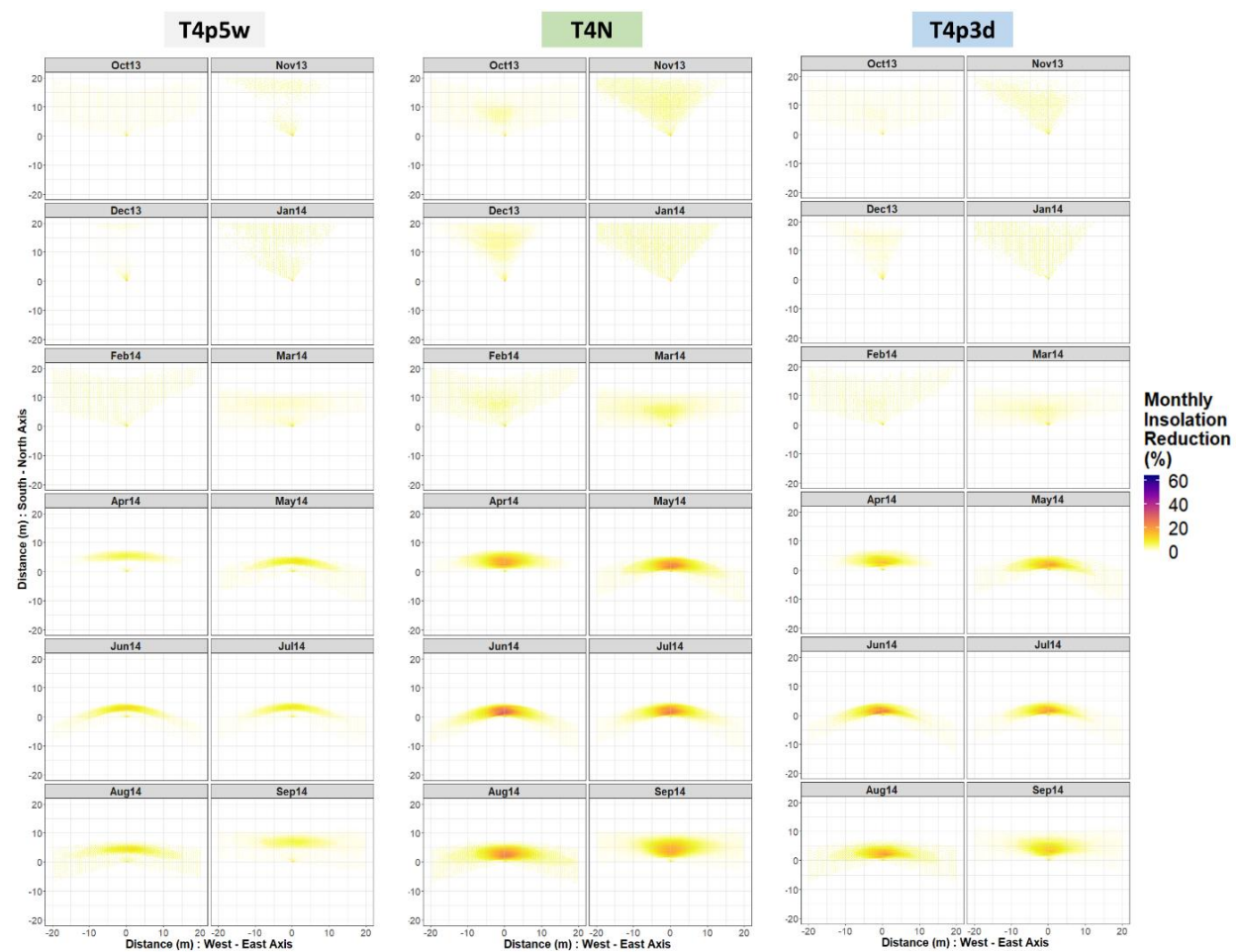


Fig. S3 Monthly shading effects for T4 (N; centre) and the low-intensity pruned trees: conventionally pruned (p5w; left), and; selectively pruned pruning (p3d; right)

Table S1 QSM-derived tree parameters for the four unpruned wild cherry trees (T1 to T4)

Attribute	T1	T2	T3	T4
DBH (cm)	11.6	9.1	14.6	12.0
Tree height (m)	7.79	8.15	10.58	9.12
Total tree volume (litres)	92.4	55.9	221.0	116.1
Original Cylinder count	6089	3773	11888	8763
Simplified Cylinder count ^a	-	1962	3404	2588
Cumulative branch length (m)	340.88	212.73	735.91	516.52
Branch volume share (%)	54.84	54.84	60.14	56.26
Max. branch order	5	5	6	6
Branch count	596	322	1098	983

^a using the *simplify_qsm* function to reduce cylinder numbers

Table S2 Summary of crown foliage dynamics of unpruned and prune tree structures

Tree	Total Leaf area (m ²)				Leaf count	Leaf count per leaf size classes ^a			
	April	May	June	July-Sept.		April	May	June	July - September
T1N	42.04	55.30	63.07	64.70	19985	6532 13453	4380 9011 6594	3785 7680 5903 2617	3735 7708 5484 2496 562
T1p3d	17.07	22.53	25.81	26.53	8111	2649 5462	1757 3644 2710	1475 3164 2346 1126	1434 3170 2231 1024 252
T1p2d	10.77	14.28	16.10	16.66	5128	1686 3442	1071 2356 1701	1008 1974 1455 691	975 1935 1414 648 156
T1p5w	8.07	10.40	11.91	12.29	3785	1169 2616	851 1710 1224	716 1481 1089 499	710 1434 1052 492 97
T1p3w	1.46	1.94	2.10	2.31	707	247 460	157 324 226	166 270 203 68	137 263 191 88 28
T2N	23.81	31.20	35.72	36.74	11325	3713 7612	2530 5104 3691	2126 4416 3285 1498	2155 4285 3108 1459 318
T2p3d	7.87	10.36	11.76	12.22	3740	1222 2518	801 1717 1222	708 1476 1058 498	707 1408 1011 495 119
T2p2d	4.00	5.24	5.89	6.20	1912	637 1275	441 849 622	387 764 524 237	364 731 510 252 55
T2p5w	6.83	8.95	10.25	10.68	3246	1060 2186	739 1428 1079	604 1270 945 427	566 1250 919 406 105
T2p3w	2.06	2.76	2.99	3.16	969	304 665	193 424 352	195 389 263 122	179 365 271 130 24
T3N	77.95	102.74	116.34	121.25	37038	12086 24952	8019 16727 12292	7056 14512 10620 4850	6753 14102 10270 4751 1162
T3p3d	11.93	15.84	17.83	18.72	5676	1862 3814	1154 2648 1874	1086 2238 1588 764	1014 2114 1626 759 163
T3p2d	6.07	8.04	9.11	9.49	2901	968 1933	621 1327 953	551 1129 851 370	515 1125 813 356 92
T3p5w	7.50	9.87	11.18	11.67	3571	1178 2393	764 1655 1152	693 1410 987 481	664 1320 1027 462 98
T3p3w	1.64	2.06	2.50	2.50	777	249 528	196 360 221	144 286 235 112	158 287 208 107 17
T4N	55.19	72.24	82.44	85.36	26179	8482 17697	5741 11931 8507	4900 10369 7412 3498	4828 9944 7308 3339 760
T4p3d	25.06	33.16	37.54	38.84	11965	3985 7980	2592 5423 3950	2296 4702 3382 1585	2253 4573 3267 1515 357
T4p2d	12.17	15.84	18.01	18.59	5717	1772 3945	1266 2539 1912	1042 2294 1639 742	1066 2173 1591 720 167
T4p5w	16.56	21.78	24.70	25.60	7865	2562 5303	1707 3567 2591	1451 3143 2279 992	1462 3017 2146 998 242
T4p3w	4.27	5.67	6.40	6.68	2036	672 1364	412 965 659	380 804 593 259	362 779 580 248 67

^a Leaf size classes (Bohn Reckziegel et al. 2021): extra-small; small; middle; large, and; extra-large.

Table S3 Retained and removed woody volume for each pruned tree structure, in relation to control tree

Tree ID	Tree Volume litres	Removed Branch volume ^a litres	Relative Tree Volume Removal %	Leaf Area m ²	Relative Leaf Area %
T1N	92.41	-	-	64.70	100.0
T1p3d	56.97	35.45	38.4	26.53	41.0
T1p2d	49.59	42.83	46.3	16.66	25.8
T1p5w	53.35	39.07	42.3	12.29	19.0
T1p3w	43.22	49.19	53.2	2.31	3.6
T2N	56.10	-	-	36.74	100.0
T2p3d	32.75	23.35	41.6	12.22	33.3
T2p2d	29.14	26.96	48.1	6.20	16.9
T2p5w	34.73	21.37	38.1	10.68	29.1
T2p3w	28.03	28.07	50.0	3.16	8.6
T3N	222.87	-	-	121.25	100.0
T3p3d	101.95	120.92	54.3	18.72	15.4
T3p2d	94.00	128.86	57.8	9.49	7.8
T3p5w	103.22	119.65	53.7	11.67	9.6
T3p3w	90.93	131.94	59.2	2.50	2.1
T4N	116.99	-	-	85.36	100.0
T4p3d	78.82	38.17	32.6	38.84	45.5
T4p2d	62.32	54.67	46.7	18.59	21.8
T4p5w	73.30	43.68	37.3	25.60	30.0
T4p3w	56.94	60.05	51.3	6.68	7.8

^a Unpruned branch volume (litres): T1N: 50.67; T2N: 30.84; T3N: 134.79; T4N: 66.21

Table S4 Shading effects of unpruned and pruned tree structures found for the simulation period of October 2013 to September 2014

Tree	Shaded Area	Mean Insolation on Shadow	Mean Insolation Reduction	Total Insolation Reduction	Mean Relative Insolation Reduction	Mean Daily Insolation ^a	Mean Daily Insolation Reduction
	m²	MJ m⁻²	MJ m⁻²	MJ	%	MJ m⁻² day⁻¹	MJ m⁻² day⁻¹
T1N	333.54	4,258.63	162.94	54,345.85	3.69	11.67	0.45
T1p3d	262.43	4,277.28	144.28	37,863.78	3.26	11.72	0.40
T1p2d	227.60	4,289.20	132.36	30,125.06	2.99	11.75	0.36
T1p5w	220.71	4,315.09	106.47	23,499.50	2.41	11.82	0.29
T1p3w	136.84	4,325.48	96.08	13,147.82	2.17	11.85	0.26
T2N	296.94	4,274.30	147.26	43,727.37	3.33	11.71	0.40
T2p3d	201.43	4,293.21	128.35	25,853.90	2.90	11.76	0.35
T2p2d	173.37	4,311.25	110.31	19,124.98	2.49	11.81	0.30
T2p5w	217.65	4,314.61	106.96	23,279.05	2.42	11.82	0.29
T2p3w	144.33	4,325.56	96.01	13,856.82	2.17	11.85	0.26
T3N	460.78	4,247.47	174.10	80,219.50	3.94	11.64	0.48
T3p3d	274.54	4,292.48	129.08	35,438.46	2.92	11.76	0.35
T3p2d	223.07	4,304.38	117.19	26,141.08	2.65	11.79	0.32
T3p5w	246.56	4,317.50	104.06	25,657.47	2.35	11.83	0.29
T3p3w	174.13	4,325.32	96.24	16,758.95	2.18	11.85	0.26
T4N	373.57	4,259.11	162.45	60,687.69	3.67	11.67	0.45
T4p3d	308.69	4,279.12	142.44	43,969.39	3.22	11.72	0.39
T4p2d	252.69	4,292.90	128.67	32,512.47	2.91	11.76	0.35
T4p5w	277.63	4,305.46	116.10	32,232.50	2.63	11.80	0.32
T4p3w	193.04	4,321.19	100.37	19,376.25	2.27	11.84	0.27

^a Total insolation under "full light conditions" of 4,421.56 MJ m⁻² and 12.11 MJ m⁻² day⁻¹ for the simulated period.

Table S5 Shaded area of all trees and area share of shade intensity classes

Tree	Shaded area	Area per Shade Intensity Classes (m ²)					Area share of Shade Intensity Classes (%)				
	%	2-5%	5-10%	10-15%	15-20%	>20%	2-5%	5-10%	10-15%	15-20%	>20%
T1N	100.0	278.79	32.47	16.23	6.02	0.03	83.59	9.73	4.87	1.80	0.01
T1p3d	78.7	225.81	26.71	9.69	0.19	0.03	86.05	10.18	3.69	0.07	0.01
T1p2d	68.2	202.49	20.53	4.41	0.14	0.03	88.97	9.02	1.94	0.06	0.01
T1p5w	66.2	218.10	2.52	0.05	0.02	0.02	98.82	1.14	0.02	0.01	0.01
T1p3w	41.0	136.34	0.41	0.05	0.02	0.02	99.63	0.30	0.04	0.01	0.01
T2N	100.0	257.31	26.46	11.38	1.77	0.02	86.65	8.91	3.83	0.60	0.01
T2p3d	67.8	181.17	16.63	3.61	0.00	0.02	89.94	8.26	1.79	0.00	0.01
T2p2d	58.4	165.98	7.31	0.06	0.00	0.02	95.74	4.22	0.03	0.00	0.01
T2p5w	73.3	215.21	2.40	0.02	0.00	0.02	98.88	1.10	0.01	0.00	0.01
T2p3w	48.6	144.06	0.23	0.02	0.00	0.02	99.81	0.16	0.01	0.00	0.01
T3N	100.0	374.99	53.35	23.23	9.17	0.04	81.38	11.58	5.04	1.99	0.01
T3p3d	59.6	248.83	22.21	3.45	0.01	0.04	90.64	8.09	1.26	0.00	0.01
T3p2d	48.4	208.46	13.84	0.72	0.01	0.04	93.45	6.20	0.32	0.00	0.02
T3p5w	53.5	245.84	0.58	0.09	0.01	0.04	99.71	0.24	0.04	0.00	0.02
T3p3w	37.8	173.41	0.58	0.09	0.01	0.04	99.59	0.33	0.05	0.01	0.02
T4N	100.0	312.62	39.20	15.75	5.98	0.02	83.68	10.49	4.22	1.60	0.01
T4p3d	82.6	268.90	30.45	9.30	0.02	0.02	87.11	9.86	3.01	0.01	0.01
T4p2d	67.6	227.91	20.93	3.81	0.02	0.02	90.19	8.28	1.51	0.01	0.01
T4p5w	74.3	265.23	12.30	0.06	0.02	0.02	95.53	4.43	0.02	0.01	0.01
T4p3w	51.7	192.53	0.41	0.06	0.02	0.02	99.74	0.21	0.03	0.01	0.01

Table S6 Spatial association measures and correlation coefficients for paired-observations (N against pruned trees) and stats

Tree	Comparison	SSS _x	SSS _y	r weights	r pearson	L_{xy}	MC simulations (N)	Pseudo-p value	Alternative Hypothesis
T1	N-p3d	0.530	0.487	0.918	0.974	0.498	1000	0.001	greater
T1	N-p2d	0.530	0.459	0.711	0.911	0.455	1000	0.001	greater
T1	N-p5w	0.530	0.444	0.312	0.714	0.382	1000	0.001	greater
T1	N-p3w	0.530	0.277	0.155	0.532	0.243	1000	0.001	greater
T2	N-p3d	0.513	0.461	0.845	0.933	0.454	1000	0.001	greater
T2	N-p2d	0.513	0.416	0.625	0.873	0.420	1000	0.001	greater
T2	N-p5w	0.513	0.462	0.469	0.799	0.424	1000	0.001	greater
T2	N-p3w	0.513	0.280	0.154	0.534	0.243	1000	0.001	greater
T3	N-p3d	0.593	0.521	0.731	0.879	0.494	1000	0.001	greater
T3	N-p2d	0.593	0.448	0.604	0.811	0.427	1000	0.001	greater
T3	N-p5w	0.593	0.419	0.127	0.587	0.353	1000	0.001	greater
T3	N-p3w	0.593	0.275	0.072	0.437	0.209	1000	0.001	greater
T4	N-p3d	0.554	0.550	0.946	0.979	0.541	1000	0.001	greater
T4	N-p2d	0.554	0.505	0.810	0.925	0.493	1000	0.001	greater
T4	N-p5w	0.554	0.551	0.467	0.777	0.465	1000	0.001	greater
T4	N-p3w	0.554	0.369	0.177	0.607	0.332	1000	0.001	greater

Table S7 Time control of simulations with the *shadow model*

Tree	Cylinder Count	Leaf Count	Simulation time (hours) ^a							
			Oct-Dec2013	Jan-Mar2014	Apr 14	May14	Jun 14	Jul 14	Aug 14	Sep 14
T1N	6089	19985	20.8	22.8	40.8	46.8	46.7	49.2	43.1	36.6
T1p3d	1672	5128	9.2	8.9	11.6	12.9	13.8	15.0	12.2	10.9
T1p2d	2584	8111	13.2	12.2	17.7	20.4	19.9	20.6	18.6	16.0
T1p5w	243	707	2.9	3.5	2.5	2.9	3.0	2.8	2.6	2.3
T1p3w	1084	3785	5.8	6.7	8.0	9.4	11.3	9.7	8.7	7.5
T2N	1962	11307	8.8	10.7	19.7	23.5	23.4	23.5	20.9	17.6
T2p3d	379	1912	4.9	4.2	4.6	5.0	5.3	5.3	5.1	4.0
T2p2d	732	3740	5.3	5.8	7.9	8.6	8.7	8.6	7.9	6.6
T2p5w	174	969	2.9	NA	2.6	3.0	3.1	3.1	2.8	2.3
T2p3w	535	3246	NA	NA	6.2	7.3	7.2	7.5	6.8	5.5
T3N	3404	37038	NA	15.2	63.3	70.0	70.0	72.3	66.7	56.2
T3p3d	591	5676	4.9	4.0	5.7	6.6	6.7	6.8	6.5	4.9
T3p2d	314	2901	5.8	5.2	9.7	11.5	11.3	11.4	10.4	8.7
T3p5w	79	777	NA	2.8	2.2	2.6	2.7	2.5	2.4	2.0
T3p3w	314	3571	NA	3.7	6.2	7.9	8.2	7.5	6.6	5.7
T4N	2588	26179	NA	12.2	43.3	50.6	49.1	49.8	47.1	40.2
T4p3d	609	5717	5.5	5.1	10.4	11.4	12.7	12.3	10.8	8.9
T4p2d	1203	11965	8.4	7.7	20.3	22.4	23.9	22.4	21.3	17.2
T4p5w	202	2036	NA	3.2	4.1	4.8	4.8	5.0	4.4	3.7
T4p3w	726	7865	NA	5.4	12.9	15.6	15.4	15.9	14.0	11.9

^a Number of sun positions (every 10 minutes): Oct-Dec13, 5149; Jan-Mar14, 5496; Apr, 2432, May, 2790; Jun, 2847; Jul, 2864; Aug, 2616; Sep, 2231.

References

Bohn Reckziegel, Rafael; Larysch, Elena; Sheppard, Jonathan P.; Kahle, Hans-Peter; Morhart, Christopher (2021): Modelling and Comparing Shading Effects of 3D Tree Structures with Virtual Leaves. In: *Remote Sensing* 13 (3). DOI: 10.3390/rs13030532.