The seasonal variation in the natural rooting capacity of cuttings of Norway Spruce and Sitka Spruce

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This report deals with a series of experiments made at the Royal Veterinary- and Agricultural College's Arboretum, Hörsholm, Denmark, during the years 1944 to 1949. Some observations made at the Institut de Populiculture, Union Allumettière, Grammont, Belgium, from 1949 to 1950 are also included. Although it is several years since these experiments were made, it should be useful to publish the results now, because they bring out certain facts of interest for the general problem of rooting spruce cuttings.

Several authors have described a seasonal variation in the rooting capacity of the spruces e. g. DEUBER (1940), FARRAR and GRACE (1941), and some of their observations differed greatly from our former observations (MUHLE LARSEN, 1946). Because the experiments made from 1940 to 1944 were not especially designed for studying this seasonal variation, we were not able to explain these differences. Therefore in 1944–45 and in 1947–48 series of cuttings of Norway spruce and Sitka spruce were collected and planted during different seasons and detailled observations were made on the rooting and shootgrowth of the cuttings. These experiments and the results from them are now described, and an attempt is made to explain the causes of the seasonal variation in the natural rooting ability of spruce cuttings.

A. The plant material and the experimental methods

The plant material. Young twigs of the current growth were collected from lateral branches of Norway spruce and Sitka spruce during the season. The trees used for the experiments were about 11 years old in 1944 and within each of the four series only cuttings from a single tree were used, so as to eliminate any influence of clonal variations on the rooting responses. The trees were growing in the Arboretum at Hörsholm, near the nurseries. During 1944–45 the first two series of cuttings were taken, each of them consisting of 12 collections of cuttings taken during the period July 6th, 1944 to May 4th, 1945. Each time 30 lateral shoots and 10 terminal shoots were collected from the Norway spruce and from the Sitka spruce. The two last series were prepared in 1947–48 being collected every fortnight (except in the month of May 1948) during the period June 11th, 1947 to September 1st, 1948, making a total of 26 collections of each species. Thirty lateral and 10 terminal shoots were taken each time from the Norway spruce, but from the Sitka spruce only lateral shoots of suitable length were available, and only 20 per collection.

The entire cutting material was taken about ½ to 1% m. above the ground on the Norway spruce, and about 1 to 2 m. above the ground on the Sitka spruce, to eliminate the influence of the position of the material on the trees on the rooting responses. Positional influence had been reported by GRACE (1939) and more recently by RUNQUIST and STEFANSSON (1950), but seems in the manner indicated to have been excluded in the present investigations.

The Treatment of the Cuttings and the Rooting medium. The cuttings were all prepared as shoots in full length with a clean cut just at the union with the second year wood. and they were immediately planted in cold frames without any treatment with growth-substances or other chemical products. The use of cuttings without heels was quite in accordance with my former experiences (MUHLE LARSEN, 1943) as well as those of DEUBER and FARRAR (1940) and GRACE (1942). The rooting medium was coarse sand, about 10 centimeters in depth, placed on a layer of peat-moss to give a more constant moisture supply to the sand. The frames were covered with white-painted „lights“, which were shaded during the whole period of experiment. Sprinkling with tap-water was done just after the planting and later on as necessary. The „lights“ were kept closed during the whole of the experimental period.

No examination of the cuttings was carried out before the final assessments were made. For the series of 1944–45 these assessments were made at the beginning of September 1945, about 14 months after the planting of the first collection, but only about four months after the planting of the last one. The series of 1947–48 were examined at the end of August 1948.

When assessing the material, all the cuttings were lifted very carefully, and a separate description was made of each cutting. The number of roots and new shoots were recorded and the length of the roots and the new shoots as well as the length of the original cuttings were measured. Samples of the cutting material were photographed, and then the experiment was finished as regards the two series from 1944–45. After assessing the cuttings from the series 1947–48, nearly all living material was replanted; the cuttings with the best root systems in the open ground, the remainder of the rooted cuttings as well as all cuttings without roots in cold frames. Although this procedure must be regarded as a very unfavourable one for the cuttings, only a very small percentage of the cuttings died during the following year, and on August 28th, 1949, a new assessment was made. Because the first assessment and the following transplanting had severely disturbed the root systems as well as the normal development of the cuttings, the second assessment only gives some minimal-values for the number of cuttings which had rooted, as well as some values for the surviving cuttings.

The recorded values from the series of 1944–45 and 1947–48 are given in Tables 1 and 2 respectively. Figure 1 consists of photographs of different collections from the 1947–48 series.

B. The Results

The first assessment. In both the first series from 1944–45 and in the final series from 1947–48 the total number of dead cuttings at the end of the experiments was highest for Sitka spruce, for which the figures are 10.7 and 5.6 percent respectively. The corresponding values for the Norway spruce were 4.6 and 1.2 percent. Thus the Norway spruce in the final series succeeded extremely well. The number of dead cuttings was not equally spread among the different collections during the year, but was especially concentrated among those cuttings collected in winter time.

Considering that some of the collections were taken and planted during frosty periods, a possible explanation is that the cuttings had not been in very close contact with the soil after planting, and for that reason they dried out more easily.

As regards the rooting of the cuttings (which is shown in Tables 1 and 2 by means of the number and the percentage of rooted cuttings given separately for each collection), the best results were obtained in the final experiments from 1947-48. Seasonal variation in rooting capacity had been observed in both the first and the final series and for both of the series. As an example we will follow what happened with the lateral shoots of Norway spruce in the 1947-48 series (Table 2). When assessed at the end of August 1948 we found that nearly all the cuttings from June and July 1947 had rooted, but in the following period the number of rooted cuttings decreased quickly and reached a minimum in the middle of September, with 10 percent rooted cuttings. RUNQUIST and STEFANSSON (1950) also obtained a minimum of rooting (0 %) in the middle of September. Afterwards the rooting increased slowly and in an irregular way during the winter months reaching in the middle of April a new maximum of 87 percent rooted cuttings. At this time the twigs on the tree, from which the cuttings were collected, began to flush, and for this reason there was a break in the collection until the first of June. In this June collection barely three months later 80 percent rooted cuttings were assessed. In the collection from June 15th however only 17 percent cuttings with roots were obtained owing to the very short period be-

Table 1. — Spruce cuttings inserted in cold frames in the experiments 1944—45, all assessed in the beginning of September 1945

Cuttings planted		Number of cuttings						Mean values			Number of				
			living												
				with roots											
Date	Number	dead	without roots	n	%	Number of roots	Total lengths of roots, cm	Number of roots per cutting	Lengths of roots per cutting, cm	Lengths of roots, cm	Cuttings with new shoot growth	new shoots	Total lengths of new shoots, cm	Number of new shoots per cutting	Mean lengths of new shoots, cm
Norway spruce, lateral shoots:															
6. 7. — 1944	30	0	17	13	43	42	123	3.2	9.5	3.0	30	107	321	3.6	3.0
2. 8.	30	0	15	15	50	50	136	3.3	9.1	2.7	29	118	319	4.1	2.7
28. 8.	30	1	18	11	37	24	81	2.2	7.4	3.4	27	79	270	2.9	3.4
18. 9.	30	0	19	11	37	21	18	1.9	1.6	0.9	29	81	170	2.8	2.1
12. 10.	30	1	23	6	20	13	16	2.2	2.7	1.2	27	77	223	2.9	2.9
9. 11.	30	0	21	9	30	15	12	1.7	1.3	0.8	30	78	216	2.6	2.8
23. 11.	30	0	20	10	33	26	60	2.6	6.0	2.3	28	64	156	2.3	2.4
15. 12.	30	0	19	11	37	12	11	1.1	1.0	0.9	28	55	128	2.0	2.3
8. 1. — 1945	30	6	21	3	10	7	68	2.3	22.7	9.4	18	28	83	1.6	3.0
15. 2.	30	8	18	4	13	8	69	2.0	17.2	8.6	12	22	59	1.8	2.7
8. 3.	30	0	14	16	53	46	171	2.9	10.6	3.7	27	75	211	2.8	2.8
4. 5.	30	1	8	21	70	55	62	2.6	3.0	1.1	27	75	174	2.8	2.3
Total number	360	17	213	130											
Percentage		5	59	36											
Norway spruce, terminal shoots:															
6. 7. — 1944	10	0	3	7	70	31	35	4.4	5.0	1.1	10	59	138	5.9	2.3
2. 8.	10	1	5	4	40	13	51	3.3	12.8	3.9	8	35	101	4.4	2.9
28. 8.	10	3	7	0	0	0	0	—	—	—	6	17	37	2.8	2.2
18. 9.	10	0	6	4	40	16	23	4.0	5.8	1.4	10	52	160	5.2	3.1
12. 10.	10	1	8	1	10	1	0	1.0	—	—	9	43	162	4.6	3.8
9. 11.	10	0	9	1	10	1	0	1.0	—	—	10	41	159	4.1	3.9
23. 11.	10	0	10	0	0	0	0	—	—	—	10	36	80	3.6	2.2
15. 12.	10	0	8	2	20	7	15	3.5	7.5	2.1	10	34	85	3.4	2.5
8. 1. — 1945	10	0	8	2	20	4	3	2.0	1.5	0.8	10	29	96	2.9	3.3
15. 2.	10	0	4	6	60	24	112	4.0	18.7	4.6	10	38	101	3.8	2.7
8. 3.	10	0	7	3	30	16	89	5.3	27.7	5.6	10	42	127	4.2	3.0
4. 5.	10	0	7	3	30	15	44	5.0	14.7	2.9	9	23	57	2.6	2.5
Total number	120	5	82	33											
Percentage		4	68	28											
Sitka spruce, lateral shoots:															
6. 7. — 1944	30	0	13	17	57	56	169	3.3	9.9	3.0	4	4	7	1.0	1.8
2. 8.	30	1	0	29	97	88	428	3.0	14.8	4.9	7	10	44	1.4	4.4
28. 8.	30	2	9	19	63	48	316	2.5	16.6	6.6	2	3	4	1.5	1.3
18. 9.	30	0	11	19	63	49	131	2.5	6.9	2.6	4	4	8	1.0	2.0
12. 10.	30	1	17	12	40	18	7	1.5	0.6	0.4	1	2	6	2.0	3.0
9. 11.	30	5	19	6	20	10	11	1.7	1.8	1.1	0	0	0	—	—
23. 11.	30	9	10	11	37	19	81	1.7	7.4	4.3	2	2	5	1.0	2.5
15. 12.	30	10	13	7	23	12	59	1.7	8.4	4.9	1	1	4	1.0	4.0
8. 1. — 1945	30	1	21	8	27	13	79	1.6	9.9	6.1	1	1	3	1.0	3.0
15. 2.	30	0	8	22	73	51	308	2.3	14.0	6.0	5	5	15	1.0	3.0
8. 3.	30	2	11	17	57	51	206	3.0	12.1	4.0	19	26	71	1.4	3.1
4. 5.	30	3	19	8	27	20	40	2.5	5.0	2.0	16	24	52	1.5	2.2
Total number	360	34	151	175											
Percentage		9	42	49											
Sitka spruce, terminal shoots:															
6. 7. — 1944	10	0	4	6	60	27	86	4.5	14.3	3.2	4	14	45	3.5	3.2
2. 8.	10	1	3	6	60	27	178	4.5	30.0	6.6	4	14	51	3.5	3.9
28. 8.	10	0	0	10	100	31	177	3.1	17.7	5.7	4	9	24	2.3	2.7
18. 9.	10	1	2	7	70	24	49	3.4	7.0	2.0	5	9	34	1.8	3.8
12. 10.	10	0	2	8	80	19	5	2.4	0.6	0.3	5	7	23	1.6	3.3
9. 11.	10	2	4	4	40	11	6	2.8	1.5	0.6	2	3	12	1.5	4.0
23. 11.	10	3	6	1	10	1	0[1])	1.0	—	0[1])	0	0	0	—	—
15. 12.	10	6	4	0	0	0	0	—	—	—	0	0	0	—	—
8. 1. — 1945	10	1	9	0	0	0	0	—	—	—	3	4	9	1.3	2.3
15. 2.	10	0	10	0	0	0	0	—	—	—	4	5	16	1.3	3.2
8. 3.	10	2	7	1	10	3	0[1])	3.0	—	0[1])	7	15	27	2.1	1.9
Total number	110	16	51	43											
Percentage		15	46	39											

[1]) Lengths < 0.5 cm

Table 2. — Spruce cuttings inserted in cold frames in the experiments 1947—48

Cuttings planted		First assessment at the end of August 1948															Second assessment at the end of August 1949			
		Number of cuttings				Number of roots	Total lengths of roots, cm	Mean values			Number of		Total lengths of new shoots, cm	Number of new shoots per cutting	Mean lengths of new shoots, cm	Number of cuttings			
		dead	living																
			without roots	with roots												dead or not transplanted	without roots	with roots	
Date	Number			n	%			Number of roots per cutting	Lengths of roots per cm	Mean lengths of roots, cm	cuttings with new shoot growth	new shoots						n	%
Norway spruce, lateral shoots:																			
11. 6. — 1947	30	1	0	29	97	108	882	3.7	30.4	8.2	20	56	205	2.8	3.8	1	0	29	97
30. 6.	30	1	0	29	97	135	1469	4.7	50.7	10.9	25	41	140	1.6	3.4	1	0	29	97
15. 7.	30	0	0	30	100	159	1489	5.3	49.7	9.4	24	33	82	1.4	2.5	0	0	30	100
29. 7.	30	0	1	29	97	167	1787	5.8	61.6	10.7	25	39	111	1.5	2.8	1	0	29	97
15. 8.	30	0	8	22	73	73	741	3.3	33.7	10.1	13	19	46	1.5	2.4	1	3	26	87
1. 9.	30	2	15	13	43	25	133	1.9	10.2	5.3	8	9	18	1.1	2.0	2	3	25	83
15. 9.	30	0	27	3	10	3	6	1.0	2.0	2.0	4	4	6	1.0	1.5	1	2	27	90
1. 10.	30	0	22	8	27	11	16	1.4	2.0	1.5	13	16	27	1.2	1.7	0	2	28	93
15. 10.	30	1	24	5	17	5	0[1])	1.0	0[1])	0[1])	13	13	23	1.0	1.8	1	8	21	70
30. 10.	30	1	23	6	20	7	14	1.2	2.3	2.0	11	11	26	1.0	2.3	1	8	21	70
20. 11.	30	1	22	7	23	14	52	2.0	7.4	3.7	13	16	28	1.2	1.8	1	10	19	63
2. 12.	30	0	14	16	53	22	63	1.4	3.9	2.9	12	14	27	1.2	1.9	2	10	18	60
18. 12.	30	0	25	5	17	6	21	1.2	4.2	3.5	15	19	37	1.3	1.9	0	9	21	70
5. 1. — 1948	30	0	16	14	47	22	124	1.6	8.9	5.6	19	30	72	1.9	2.4	1	5	24	80
17. 1.	30	0	9	21	70	40	192	1.9	9.1	4.8	22	27	57	1.2	2.1	0	9	21	70
31. 1.	30	1	12	17	57	47	155	2.8	9.1	3.3	18	25	61	1.4	2.4	1	3	26	87
16. 2.	30	0	15	15	50	30	153	2.0	10.2	5.1	11	14	17	1.3	1.2	2	7	21	70
15. 3.	30	0	8	22	73	40	167	1.8	7.6	4.2	21	29	47	1.3	1.6	0	6	24	80
14 4.	30	0	4	26	87	59	379	2.3	14.6	6.4	11	20	44	1.8	2.2	0	3	27	90
14. 4. b — c	30	0	19	11	37	18	15	1.6	1.4	0.8	30	54	102	1.8	1.9	0	4	26	87
1. 6.	30	1	5	24	80	46	147	1.9	6.1	3.2	0	0	0	0	0	1	5	24	80
15. 6.	30	1	24	5	17	7	0[1])	1.4	0[1])	0[1])	0	0	0	0	0	1	3	26	87
1. 7.	30															0	1	29	97
17. 7.	30															1	0	29	97
5. 8.	30															1	0	29	97
18. 8.	30															1	7	22	73
1. 9.	30															0	18	12	40
Norway spruce, terminal shoots:																			
11. 6. — 1947	10	0	0	10		60	406	6.0	40.6	6.8	9	32	156	3.6	4.9	0	0	10	100
30. 6.	10	0	0	10		79	647	7.9	64.7	8.2	10	29	106	2.9	3.7	0	0	10	100
15. 7.	10	0	0	10		72	760	7.2	76.0	10.5	10	22	65	2.2	3.0	0	0	10	100
29. 7.	10	0	0	10		77	711	7.7	71.1	9.2	9	23	56	2.6	2.4	0	0	10	100
15. 8.	10	0	1	9		52	303	5.8	33.7	5.8	9	18	56	2.0	3.1	0	0	10	100
1. 9.	10	0	2	8		26	143	3.3	17.9	5.5	10	13	38	1.3	2.9	0	1	9	90
15. 9.	10	0	9	1		1	0[1])	1.0	0[1])	0[1])	7	8	14	1.1	1.8	0	1	9	90
1. 10.	10	0	7	3		5	16	1.7	5.3	3.2	4	6	15	1.5	2.5	0	3	7	70
15. 10.	10	0	7	3		4	1	1.3	0.3	0.3	4	6	11	1.5	1.8	2	3	5	50
30. 10.	10	0	3	7		15	58	2.1	8.3	3.9	8	11	30	1.4	2.7	1	3	6	60
20. 11.	10	0	4	6		18	91	3.0	15.2	5.1	10	20	52	2.0	2.6	2	1	7	70
2. 12.	10	0	5	5		11	58	2.2	11.6	5.3	10	14	36	1.4	2.6	0	3	7	70
18. 12.	10	0	6	4		10	72	2.5	18.0	7.2	8	11	25	1.4	2.3	0	2	8	80
5. 1. — 1948	10	0	6	4		8	74	2.0	18.5	9.3	8	12	28	1.5	2.3	0	2	8	80
17. 1.	10	0	1	9		26	148	2.9	16.4	5.7	9	18	51	2.0	2.8	0	1	9	90
31. 1.	10	0	3	7		23	96	3.3	13.7	4.2	8	9	27	1.1	3.0	0	1	9	90
16. 2.	10	0	2	8		17	44	2.1	5.5	2.6	8	12	26	1.5	2.2	0	1	9	90
15. 3.	10	1	5	4		12	62	3.0	15.5	5.2	6	9	13	1.5	1.4	1	2	7	70
14. 4.	10	0	0	10		18	111	1.8	11.1	6.2	10	19	52	1.9	2.7	0	0	10	100
14. 4. b — c	10	0	5	5		16	31	3.2	6.2	1.9	10	30	68	3.0	2.3	0	5	5	50
1. 6.	10	0	2	8		23	67	2.9	8.4	2.9	0	0	0	0	0	0	2	8	80
15. 6.	10	0	7	3		10	29	3.3	9.7	2.9	0	0	0	0	0	0	0	10	100
1. 7.	10															0	0	10	100
17. 7.	10															0	0	10	100
5. 8.	10															0	0	10	100
18. 8.	10															1	5	4	40
1. 9.	10															1	9	0	0
Sitka spruce, lateral shoots:																			
13. 6. — 1947	20	0	1	19	95	154	619	8.1	32.6	4.0	0	0	0	0	0	1	0	19	95
30. 6.	20	0	1	19	95	76	287	4.0	15.1	3.8	6	7	20	1.2	2.9	1	0	19	95
16. 7.	20	1	3	16	80	94	661	5.9	41.4	7.1	5	8	17	1.6	2.1	1	0	19	95
29. 7.	20	0	4	16	80	67	561	4.2	35.1	8.4	5	5	15	1.0	3.0		1	19	95
15. 8.	20	0	12	8	40	23	175	2.9	21.9	7.6	2	2	6	1.0	3.0		4	16	80
1. 9.	20	0	10	10	50	45	324	4.5	32.4	7.2	2	2	5	1.0	2.5	6	4	10	50
18. 9.	20	0	12	8	40	26	39	3.3	4.6	1.5	0	0	0	0	0		8	12	60
1. 10.	20	1	16	3	15	4	5	1.3	1.7	1.3	0	0	0	0	0	2	6	12	60
15. 10.	20	0	17	3	15	5	14	1.7	3.7	2.8	2	2	3	1.0	1.5		15	5	25
30. 10.	20	1	17	2	10	5	2	2.5	1.0	0.4	0	0	0	0	0	1	6	13	65
20. 11.	20	1	18	1	5	2	1	2.0	1.0	0.5	0	0	0	0	0	1	8	11	55
2. 12.	20	0	13	7	35	12	18	1.7	2.6	1.5	0	0	0	0	0	0	5	15	75
18. 12.	20	2	14	4	20	11	21	2.8	5.3	1.9	1	1	1	1.0	1.0	2	3	15	75
5. 1. — 1948	20	1	17	2	10	6	23	3.0	11.5	3.8	0	0	0	0	0	1	9	10	50
17. 1.	20	6	6	8	40	25	81	3.1	10.1	3.2	1	1	4	1.0	4.0	6	6	8	40
31. 1.	20	5	8	7	35	13	57	1.9	8.1	4.4	1	1	1	1.0	1.0	5	0	15	75
16. 2.	20	7	8	5	25	5	7	1.0	1.4	1.4	0	0	0	0	0	8	5	7	35
15. 3.	20	1	14	5	25	8	14	1.6	2.8	1.8	8	9	16	1.1	1.8	1	1	18	90
14. 4.	20	1	7	12	60	24	67	2.0	5.6	2.8	1	1	2	1.0	3.0	1	4	15	75
14. 4. a	13	0	3	10	77	16	20	1.6	2.0	1.3	1	1	2	1.0	2.0	0	2	11	85
14. 4. b	13	0	11	2	15	7	4	3.5	2.0	0.6	12	15	[2])	—	—	6	4	3	23
14. 4. c	13	0	12	1	8	2	1	2.0	1.0	0.5	13	21	[3])	—	—	0	7	6	46
1. 6.	20	0	17	3	15	4	1	1.3	0.3	0.3	0	0	0	—	—	0	0	20	100
15. 6.	40	0	40	0	0											0	11	29	73
1. 7.	40															3	3	34	85
17. 7.	20															1	0	19	95
2. 8.	20															1	4	15	75
19. 8.	20															0	1	19	95
2. 9.	20															2	12	6	30

[1]) Lengths $<$ 0.5 cm
[2]) A part of the shoots wilthered before the assessment
[3]) All of the shoots wilthered before the assessment

tween planting and assessment of the cuttings. The five following collections (during the period 1. 7. to 2. 9. 1948) were for that reason assessed one year later, at the end of August 1949. At that time we found figures for the rooting which indicated for the months July-September 1948 the same fluctuations as those of 1947. Thus, this type of seasonal variation is in agreement with the results of GRACE (1941), who also carried out the experiments under cold frame conditions.

A similar seasonal variation in the rooting capacity was found with the terminal shoots of Norway spruce, and also with the lateral shoots of Sitka spruce, although the decrease during the autumn was slower as regards to the Sitka spruce.

The figures in the tables indicate that the number of roots also varies during the season, not only according to the variation in number of rooted cuttings, but also in such a way that the number of roots per cutting varies from one season to another.

For Norway spruce we found an increase in the number of roots per cutting from 3.7 (11/6) to 5.8 (29/7). This increase seems to be related to the degree of development of the young shoots. Then a decrease took place until the minimum 1.0 was reached (15/9). Next a slow increase in the number of roots per cutting occured until 2.3 was reached in the middle of April. Later on the number diminished because of the short interval between planting and assessment.

In assessing the lengths of the roots we found similar, but more pronounced, seasonal variations. Here the minimum for Norway spruce was reached at the beginning of October whereas the roots of the Sitka spruce reached their minimum length about one month later.

Even the formation of new shoots on the cuttings showed similar seasonal variations.

Thus all the recorded figures show a seasonal variation in the vital functions of the cuttings in the speed of development.

Only one unsuitable period for collecting the cuttings seemed to exist under the growth conditions of our experiments and that is the season when the twigs are making new growth. During that period the cuttings are very sensitive to the influence of the external conditions, and the rooting capacity seemed to decrease according to the flushing of the buds and the first elongation of the new shoots.

When collecting the cuttings in the middle of April 1948 (mostly among twigs which seemed to be latest in bud development) some additional cuttings were taken. In Sitka spruce three categories of cuttings were available: *a*, those with the buds not yet flushed; *b*, those with short, newly formed, compact shoots; and *c*, those with longer, slender shoots.

At the end of August we found that 77% of the still dormant cuttings had rooted, 15% of the newly flushed cuttings, and only 8% of the third category.

In Norway spruce, where the ordinary collection was estimated to represent the category *a*, the development of the shoots was not sufficiently advanced to permit a division between *b* and *c*. An additional collection of *b*-*c* type cuttings was prepared from among both lateral and terminal shoots. The rooting in this category was fifty or more percent lower than in the still dormant cuttings.

It has not yet been ascertained how soon the newly formed shoots can be used as cuttings; but our collections of June, 1st showed a rooting of 80 percent for the Norway spruce. In the cuttings of Sitka spruce, which seemed to root more slowly, a percentage of 15 was recorded. At this stage the new shoots of Sitka spruce were slender and weak, as can be seen in Figure 1.

The second assessment. As mentioned earlier, nearly all living cuttings from the series of 1947-48 were replanted after the first assessments had been made at the end of August 1948 and a second assessment was made on August 28th, 1949. Some details are given in Table 2, and in Table 3 the total numbers and percentages within the different parts of the cutting-types are given for cuttings which had been assessed twice.

Table 3. — Total figures for the rooting of Spruces during the period from planting until the first and the second assessments

Description		Number of planted cuttings	Category of cuttings 1947-48			1947-49		
			Dead	Living without roots	Living with roots	Dead	Living without roots	Living with roots
			Number of Cuttings					
Norway Spruce:	lateral	660	10	293	357	18	100	542
	terminal	220	1	75	144	6	31	183
	Total	880	11	368	501	24	131	725
Sitka Spruce:	lateral	479	27	281	171	43	108	328
			Percent of Cuttings					
Norway Spruce:	lateral		1.5	44.4	54.1	2.7	15.2	82.1
	terminal		0.4	34.1	65.5	2.7	14.1	83.2
	Total		1.3	41.8	56.9	2.7	14.9	82.4
Sitka Spruce:	lateral		5.6	58.7	35.7	9.0	22.5	68.5

Within Norway spruce 2.7 percent of the cuttings were dead before the second record, and within Sitka spruce 9.0 percent dead cuttings were found. The category of dead cuttings included the few weakly cuttings, which had not been transplanted after the first assessment in 1948. The total number of Norway spruce (which in 1948 had rooted with 56.9 percent) was in 1949 at 82.4 percent. The Sitka spruce showed respectively 35.7 and 68.5 percent cuttings with roots in the two assessments. Thus a big number of the cuttings rooted in the second year after planting, although a good number of living cuttings without roots were still present. The Norway spruce again showed here its quicker rooting ability when compared with Sitka spruce. Most interesting is the clear tendency to level out the seasonal variations, which were so pronounced in the 1948 assessment. Thus for example the cuttings of Norway spruce collected 15. 9. 47 increased their rooting percent from 10 in 1948 to 90 in 1949.

When assessing the cuttings in 1949 we found some examples which clearly demonstrated that cuttings, on which the roots were broken during the first assessment in 1948, formed new roots very slowly or even not at all; and there is no doubt that the figures for rooting quoted in 1949 must be read as minimum values. If we had been able to carry out the experiment with a double series of cuttings, of which some had been kept undisturbed until the second, final assessment, we should certainly have obtained a still more successful result with a higher rooting percent.

The variations in seasonal rooting ability in terminal and lateral shoots of Norway spruce as well as in the lateral shoots of Sitka spruce is demonstrated in Figure 1, where 10 cuttings from each of five collections are presented namely 30. 6. 47; 1. 10. 47; 20. 11. 47; 17. 1. 48 and 14. 4. 48. In addition, cuttings from the most advanced shoots, collected at the latest date, are shown, and also

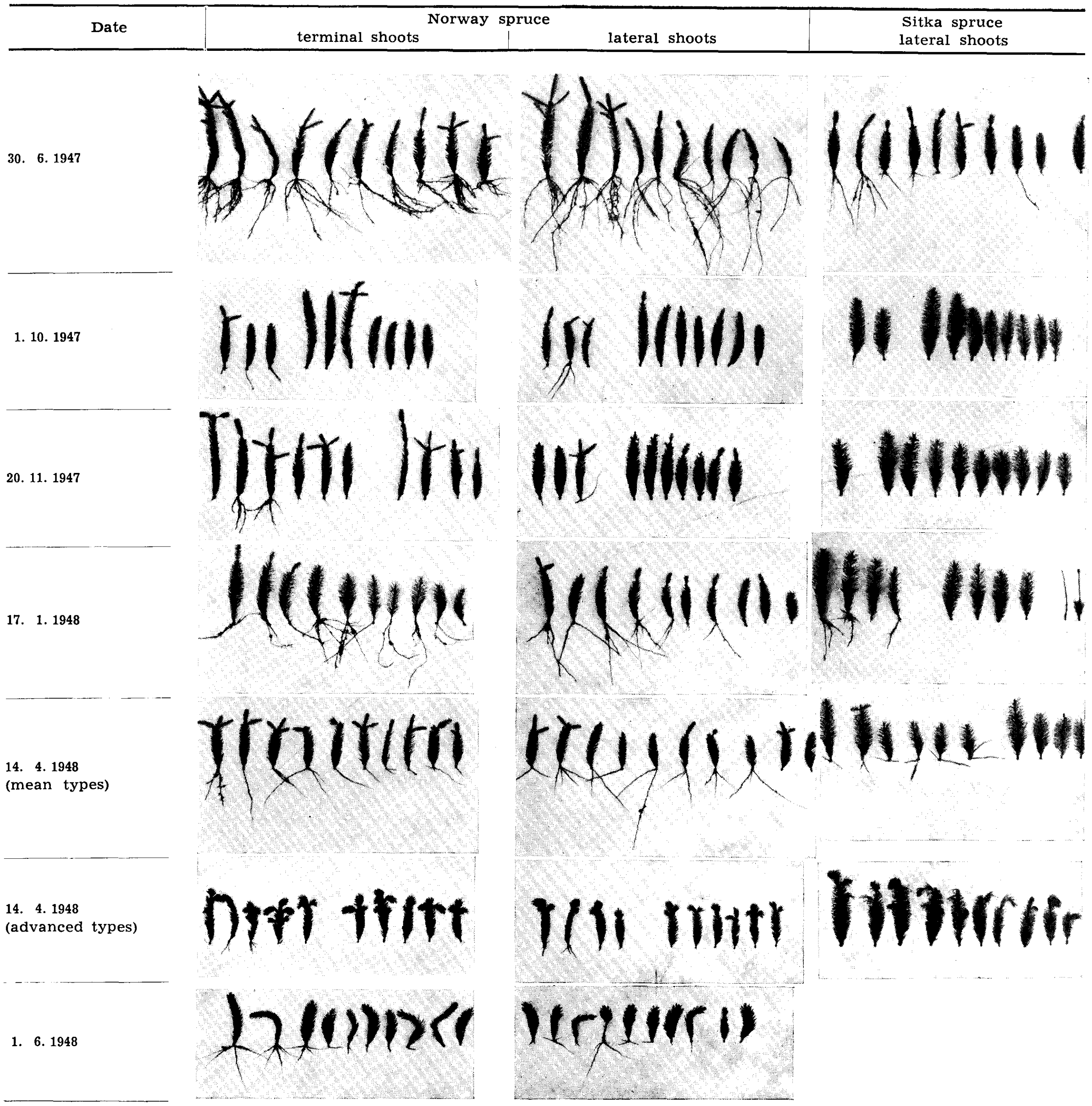

Fig. 1. — The seasonal rooting ability of spruce cuttings.

cuttings of Norway spruce from 1. 6. 48 are represented. It must be added that the photos of cuttings of Sitka spruce from 30. 6. 47 shows more new shoots than are indicated in Table 2 owing to the fact that some cuttings, of which the roots were broken, had been replaced by some others from another collection. All the photos were taken at the end of the first assessment, 2-3. 9. 1948.

In Figure 2 the seasonal variation in the rooting percent of lateral cuttings of Norway spruce is demonstrated according to the two assessments of 1948 and 1949.

The results of these experiments have demonstrated a seasonal variation in the natural rooting capacity of spruce cuttings in the four series of collections under the present external growth conditions.

This variation is not only influenced by the different length of the period from planting to assessment but seems also influenced by the nature of the cuttings and the external conditions.

The variation is firstly one of speed of rooting, and the second part of the experiment of 1947-48 indicates that the range of the variation decreases with an increasing rooting period.

Thus it has been demonstrated that the length of the period from planting to assessing the cuttings influences the results of rooting in a very important manner.

We have therefore in our discussion to distinguish between theoretical and practical conclusions.

From a practical point of view we should — under the present growth conditions — prefer to propagate the

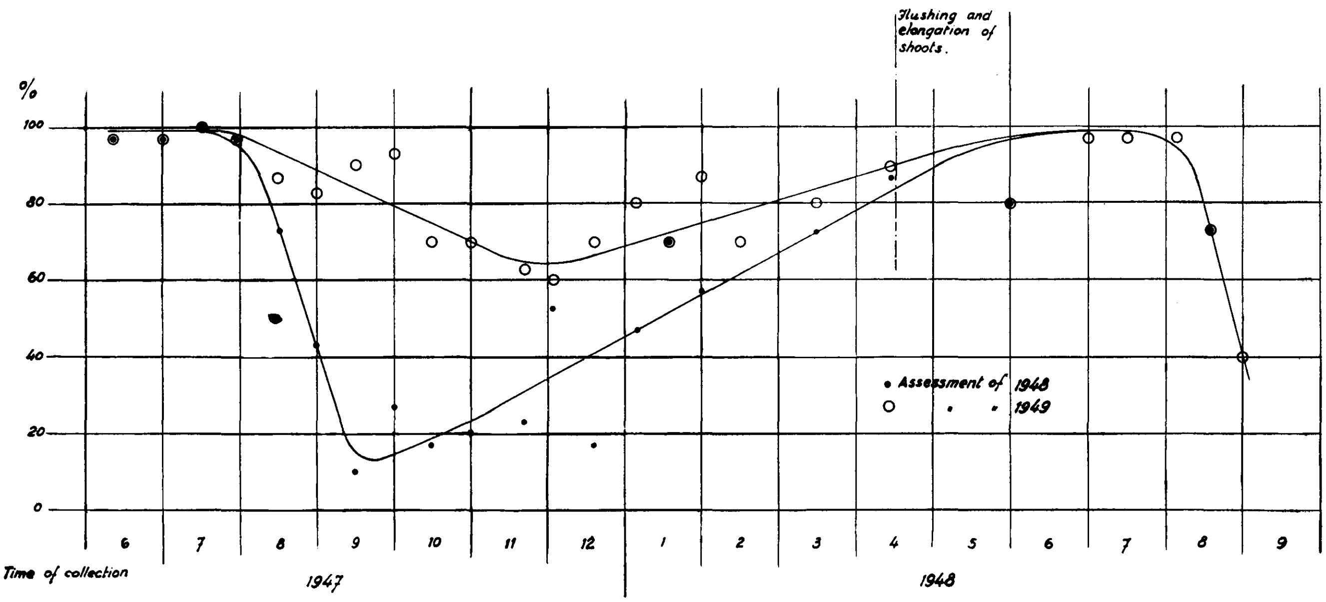

Fig. 2. — The seasonal variation in the rooting percent of lateral cuttings of Norway spruce in 1948 and 1949 assessments.

spruce in the early springtime or in the middle of summer to be sure that most of the cuttings could be rooted before the coming winter.

From a theoretical standpoint it has been demonstrated that even cuttings prepared in the less successful periods of the year are able to root to such an extent that we can postulate that under optimal propagation conditions the clones used should always be able to root even when they start under very different conditions owing to the seasonal variation in external conditions as well as in the physiological nature of the twigs.

The only critical period of the year for the rooting of the cuttings is the period of flushing or leafing out. At the present time we have not made sufficient experiments to state whether the shoots will always be able to survive and root during this period or not.

C. The Nature of the Seasonal Variation

To explain the seasonal variation in rooting ability which has been demonstrated, it should be useful to distinguish between two groups of factors which appear to influence the rooting, viz. the propagation conditions during the rooting period and the nature of the cutting material.

The first of these groups of factors, the propagation conditions during the rooting period, comprises not only the micro climatic conditions under which the rooting takes place, but also all other influences as for example the influence of the rooting medium and treatment of the cuttings before planting.

As regards the second group, the nature of the cuttings — which is of course also influenced by the propagation conditions —, this refers not only to the anatomical structure and development of the shoots but also to their content of nutrient matter and substances which directly or indirectly influence the formation of new roots.

The Propagation Conditions. Numerous publications dealing with cutting experiments on all kinds of trees and shrubs have in a general way demonstrated the influence of temperature, moisture, aeration of the rooting medium, etc.. on the rooting of cuttings. The rooting medium and the treatment of the cuttings before planting have also been examined in detail. The treatment with growth promoting substances has been investigated to a large extent in recent years.

The spruces have also been the object of studies in this field, viz. bibliography. It can further be added that watering with nutrient solutions also influences the rooting response in a positive manner (Grace, 1939). In a previous experiment of 1943 with Norway spruce (Muhle Larsen, 1946, pp. 320—326) we found that the cuttings began rooting one or two months sooner when planted in coarse sand watered with a nutrient solution than they did when planted in the same medium and given water only.

Until now we have been unable to carry out experiments with spruce cuttings under constant micro climatic conditions, but some examples given below will demonstrate in a very rough manner the influence of micro climatic conditions on rooting capacity.

At the same time as the collections of Sitka spruce were planted in cold frames during the period of 1947-48, samples (each of 42 lateral cuttings) were planted in boxes with coarse sand and placed in the greenhouses. In summertime they were under rather hot conditions and therefore (as we discovered later) had been watered too much. In winter the greenhouses were unheated. In Figure 3 the rooting ability of these samples, expressed by percentage of rooted cuttings, is compared with that of the other Sitka spruce in the cold frames. It will be seen that the percentage of rooted cuttings during the months of June and July is lower than the corresponding figures for the cold frames. During the following months the figures are higher than those of the cuttings in the cold frames owing to a milder climate, but during the period from January to the middle of February the figures follow each other very closely — corresponding with identical temperatures in the two places. In March the greenhouse conditions were the best owing to a higher temperature, but in April a decrease in the percentage of rooted cuttings was observed, undoubtedly caused by the higher fluctuations in temperature in the greenhouses.

In Table 4 some figures are given for the survival of cuttings from Norway spruce in cold frames and under greenhouse-conditions in Belgium. All the cuttings were prepared on the 10. 11. 49, but most of them were stored

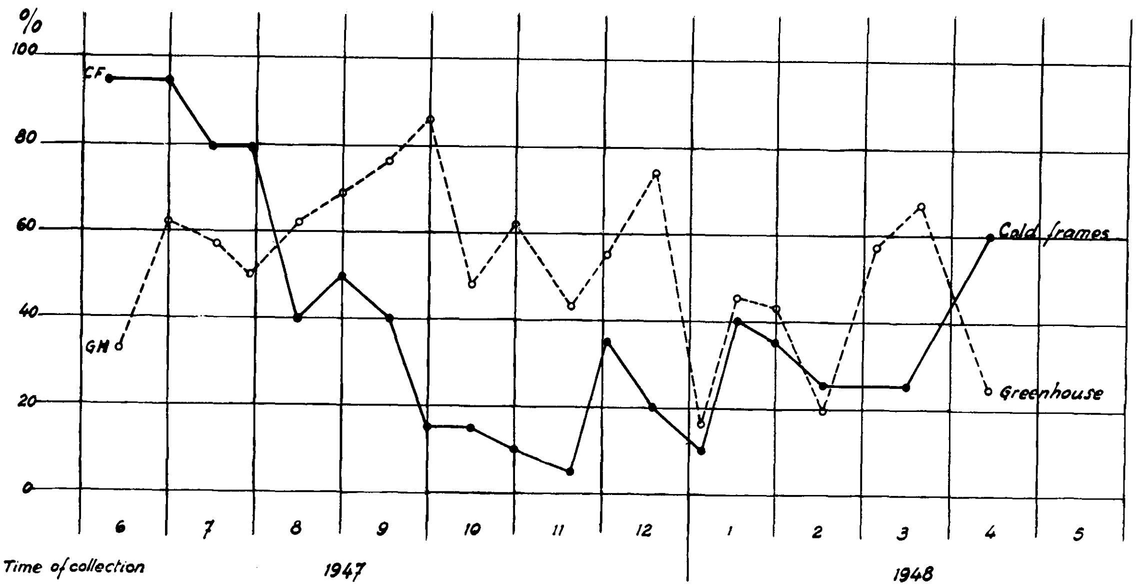

Fig. 3. — The rooting ability of samples of Sitka spruce planted in cold frames and greenhouse at the same time, expressed by percentage of rooted cuttings.

for one or two weeks in sphagnum (or water) before planting. The figures show the bad effects of high temperature combined with wide fluctuations of temperature inside the greenhouse. Because no effective regulation of temperature and moisture conditions was possible the range of temperances was much more pronounced in the greenhouses than in the cold frames. In this experiment, the rooting conditions in the greenhouses and cold frames showed a stronger effect than the influence of the treatment of the cuttings before planting.

The third example demonstrates the effect of storing the cuttings under different temperature-conditions for a certain time before planting. The figures in Table 5 originate from a preliminary experiment, carried out in 1947—1948 with cuttings of Norway spruce from the same clone as those in the seasonal series.

Each unit of the experiment comprised 40 lateral and 40 terminal cuttings. After storage under different temperatures, the cuttings were cultivated in two different places, but the figures in Table 5 give the mean values and the totals for the two groups. Lower down in the table are added the figures from the seasonal collection of 5. 1. 48. We found that the rooting process can be accelerated or retarded by the temperature-conditions under which the cuttings had been stored, even when all the cuttings were collected on the same date and thus in nearly the same stage of seasonal development.

In Table 6 the result of another preliminary experiment with cuttings of Sitka spruce is given and here the effect of the temperature is very pronounced when using a short period of storage at 30° C. Each of the samples comprised 20 cuttings. Photographs of all living material at the time assessment were made in the middle of July 1948, are found in Fig. 4. The cuttings on photos 1—8 were of the same clonal origin whereas the cuttings on photo 9 came from another clone.

There seems to be a great clonal variation in the responses to this treatment and furthermore the lateral cuttings (photos 8—7) seem to be more sensitive to the treatment than the terminal cuttings (photos 1—2).

It is true that clonal differences in rooting ability and demands for special propagation conditions can give us some trouble in propagation, but the preliminary experiment described above tempts us to presume that it should

Table 4. — The survival of cuttings of Norway Spruces after different treatments before their planting under two different growth conditions. All cuttings prepared on 10.11.1949

Planted date	Treatment before planting	Number of cuttings	Growth conditions	Number of living cuttings 1950 20.3	12.4	5.5	13.6	1951 25.5
10.11.49	—	40	Cold frame	40	40	40	40	30
	—	40	greenhouse	21	13	5	0	0
18.11.49	Sp 20° C	40	cold frame	40	40	40	39	20
	Sp 25° C	40	cold frame	40	40	40	39	17
	W 19° C	40	cold frame	40	35	27	20	4
	Sp 20° C	40	greenhouse	15	8	3	0	0
	Sp 25° C	40	greenhouse	13	4	1	0	0
28.11.49	Sp 20° C	40	cold frame	40	38	33	30	13
	Sp 19° C	40	cold frame	40	37	31	28	9
	Sp 20° C	40	greenhouse	8	7	3	0	0
	Sp 19° C	40	greenhouse	4	2	1	0	0

Sp Sphagnum W — Water

Table 5. — Variation in the rooting of Norway spruces, collected on the 5. 1. 1948 and assessed on the 14. 7. 1948, after different treatments before planting

Storage temperature	% of dead cuttings Length of treatment (Weeks) 2	4	6	9	% of cuttings with roots Length of treatment (Weeks) 2	4	6	9	Number of roots per 40 cuttings Length of treatment (Weeks) 2	4	6	9	Length of roots per 40 cuttings Length of treatment (Weeks) 2	4	6	9
5° C	—	7.5	13.5	—	—	20.0	36.5	—	—	12	21	—	—	17	80	—
15° C	0	2.5	12.5	67.5	20.0	47.5	60.0	5.0	10	34	49	7	40	149	436	52
17° C	2.5	0	45.5	—	70.0	20.0	16.0	—	60	15	6	—	252	51	48	—
30° C	—	40.0	97.5	—	—	10.0	0	—	—	5	0	—	—	13	0	—
Cold frames. Assessment of August 1948:	0				43.0				23				163			

Fig. 4. — The effect of storage temperature on cuttings of Sitka spruces (see the text and table 6). Below two samples of Norway spruce (see the text p. 79).

be possible to find an optimal treatment for rooting spruce cuttings in a way which can be of importance for practical propagation.

In summarizing the above observations we must say that the propagation conditions can influence and govern the rooting results even when the cuttings have been collected on the same date. As the environmental conditions differ greatly from one season to another, this group of factors will influence the seasonal rooting ability in a very pronounced manner. The rest of the differences in reaction of the cuttings to the season is certainly to be found in the cuttings themselves.

The Nature of the Cuttings. Among the factors which may be presumed to influence seasonal variation in the reactions of the cuttings to rooting (e. g. the anatomical structure and development of the shoots, their chemical composition and content of growth substances) only one component, the size of the cuttings, has been particularly examined in the present experiments.

We have not yet studied in detail the rooting responses during the critical period of bud-sprouting and shoot-elongation, but at the other seasons of the year the size and vigour of the shoots seems to influence the rooting ability.

From our experiments we know that cuttings of Norway spruce are able to root to an extent of 100 percent if cultivated under good environmental conditions. Thus the length of the cuttings (which in our experiments varies from 5 to 20 cm.) not always needs to be a factor of primary importance, though it was likely that the rooting ability could be influenced by this factor. Thus the length of cuttings has already been examined by Deuber and Farrar (1940) and Grace and Farrar (1945) and later by Runquist and Stefansson (1950). These authors all found the same correlation between cutting length and number of roots as described below. To confirm and generalize from these records detailed examinations of the assessments from the present experiments as well as from some older ones were carried out. The results are summarized in Table 7. Here the cutting material has been devided into three groups for length of cuttings and for each group fi-

Table 6. — The rooting of cuttings of Sitka Spruce stored under different temperatures in 1947-48, assessed during July 1948

Collection date		Period of storing at a temperature of			Percent of Cuttings living			Number of roots	Total length of roots	Photo n⁰
		30⁰ C	17⁰ C	15⁰ C	Dead	without roots	with roots			
18.12.47	*l*	18.12—22.12	22.12—17.1	—	20	25	55	26	203	4
„	*l*	id.	22.12— 5.1	—	15	25	60	20	242	6
„	*l*	—	—	18.12—17.1	60	25	15	5	18	3
„	*l*	—	—	18.12— 5.1	60	35	5	1	10	5
5.1.48	*l*	—	5.1—17.1	—	0	55	45	18	117	8
„	*l*	—	—	5.1—17.1	0	100	0	0	0	7
„	*t*	—	5.1—17.1	—	10	25	65	36	182	1
„	*t*	—	—	5.1—17.1	20	10	70	33	115	2
18.12.47	*l*	18.12—22.12	22.12— 5.1	—	15	80	5	1	0	9

l = lateral cuttings *t* — terminal cuttings

Table 7. — The influence of length of cuttings on the rooting of spruces

Description	Lateral cuttings Values for the three classes				Lateral total	Terminal cuttings Values for the three classes			Terminal total
1. *Norway spruce*, 1947-48, cold frames:									
Range of cutting lengths in cm	5—8	9—10	11—18		5—18	6—9	10—11	12—20	6—20
Total number of examined cuttings	273	238	143		654	64	88	67	219
Percent of cuttings with roots	48	52	67		54	66	57	78	66
Number of roots per cutting	1.9	2.6	4.7		3.0	2.4	4.1	5.2	4.0
Sitka spruce, 1947-48									
Range of cutting lengths in cm	5—8	9—11	12—20		5—20				
2. Cold frames:									
Total number of examined cuttings	125	237	110		472				
Percent of cuttings with roots	32	34	42		36				
Number of roots per cutting	2.5	3.6	4.8		3.6				
3. Greenhouses:									
Total number of examined cuttings	214	288	212		714				
Percent of cuttings with roots	44	59	55		53				
Number of roots per cutting	2.3	2.8	3.9		3.0				
4. *Sitka spruce*, 1944-45, cold frames:									
Range of cutting lengths in cm	8—12	13—15	16—22		8—22	11—15	16—18	19—23	11—23
Total number of examined cuttings	125	124	80		329	26	34	24	84
Percent of cuttings with roots	60	52	42		53	54	53	42	50
Number of roots per cutting	2.2	2.4	3.0		2.4	3.1	3.0	3.8	3.2
5. *Norway spruce*, 1944-45, cold frames:									
Range of cutting lengths in cm	9—11	12—15	16—22		9—22	11—14	15—19	20—24	11—24
Total number of examined cuttings	53	247	44		344	21	71	27	119
Percent of cuttings with roots	53	36	30		38	43	21	19	26
Number of roots per cutting	2.2	2.5	2.8		2.4	4.0	3.5	3.8	3.5
Norway spruce, 1943, greenhouses:									
Range of cutting lengths in cm	6—10	11—12	13—22		6—22	10—14	15—16	17—30	10—30
6. watering with water:									
Total number of examined cuttings	96	84	70		250	19	16	14	49
Percent of cuttings with roots	59	54	60		58	21	50	29	33
Number of roots per cutting	1.7	2.0	2.7		2.1	2.3	2.3	5.3	3.0
7. watering with 0.2 p. c. Nutrient solution:									
Total number of examined cuttings	98	85	67		250	16	20	14	50
Percent of cuttings with roots	74	81	84		79	69	75	100	80
Number of roots per cutting	2.4	3.0	4.9		3.3	3.0	4.4	6.8	4.7
8. watering with 0.4 p. c. Nutrient solution:									
Total number of examined cuttings	110	66	74		250	21	22	7	50
Percent of cuttings with roots	60	48	47		53	57	23	43	40
Number of roots per cutting	2.2	2.2	2.8		2.4	1.7	3.6	2.5	2.3
9. *Norway spruce*, 1947, bad growth conditions:									
Range of cutting lengths in cm	5—7	8—9	10—12	13—17	5—17				
Total number of examined cuttings	255	248	195	36	734				
Percent of cuttings with roots	22	17	6	0	15				
Number of roots per cutting	2.4	2.6	3.0	—	2.5				

gures of the total number of cuttings; the percentage of rooted cuttings and the number of roots per cutting are given. Each of the series consists of cuttings from a single tree. In all the series we found a positive correlation between length of cutting and number of roots (except in two cases where the number of examined cuttings in the group were below 10).

It is true that some of the figures in Table 7 represent mean values of several collections taken on different dates during the year and thus rooted under different environmental conditions, viz. the series 1 to 5. In using clonal material of cuttings from young trees it was not possible to obtain exactly the same length of cuttings in each collection and thus it could be presumed that the correlation between the mean figures of the series from 1 to 5 do not correspond with a similar correlation within the different parts of the series. Examinations within smaller parts of the series representing one to four collections cultivated under nearly comparable environmental conditions showed however a similar correlation as we found in the mean figures for the whole series, whether the cuttings were collected for example in June-July 1947, January-March 1948 or June 1948. Only in the „critical" season do we find no positive correlation due to the fact that the number of cuttings examined was very small and that the climatic conditions in this period were very varied. The figures for the analysis of lateral cuttings of Norway spruce in the series 1947-48 are given in Table 8.

Table 8. — Relation between length of cutting and the number of roots per cutting (*m*) in lateral cuttings of Norway Spruce. Number of rooted cuttings (*n*) is indicated within each group

Norway Spruce lateral cuttings (vide Table 2)	g. c.[1]	Length of cuttings in centimeters 5—7		8—9		10—12		13—15		16—18		Total	
		n	*m*	*n*	*m*	*n*	*m*	*n*	*m*	*n*	*m*	*n*	*m*
11.6- 29.7 1947	*U*	6	2.0	22	3.8	36	4.4	49	5.7	4	9.5	117	4.9
15.8- 1.9 „	*V*	0	—	10	3.3	17	2.4	7	3.3	1	1.0	35	2.8
15.9-30.10 „	*V*	—	—	6	1.5	13	1.1	1	1.0	2	1.0	22	1.2
20.11-18.12 „	*V*	4	2.3	14	1.4	10	1.4	0	—	—	—	28	1.5
5.1- 17.1 1948	*U*	3	1.3	8	1.6	20	1.8	3	2.0	1	3.0	35	1.8
31.1- 16.2 „	*U*	12	2.2	15	2.3	5	3.2	—	—	—	—	32	2.4
15.3- 14.4 „	*U*	17	1.7	27	2.1	4	3.0	—	—	—	—	48	2.1
1.6- „	*U*	7	1.6	13	1.6	4	3.5	—	—	—	—	24	1.9

[1]) g. c. = growth conditions *V* = ± varying *U* = ± uniform

The series 6—8 (in Table 7) show us a similar influence of cutting length on the number of roots within the same period of rooting but under different watering conditions; and the figures from series 9 which represent cuttings planted in the summer but grown under extremely bad conditions show the same tendency.

The influence of cutting length on rooting seems to be well explained by the fact that the longer cuttings possess a relatively much higher weight and thus certainly more reserves of organic matter necessary for the formations of new roots.

Because the number of roots is nearly the same whether the rooting has been assessed after 3 months or 14 months, we may even assume that the development of roots takes place within an even shorter period depending on the environmental conditions, (this is confirmed by the results of GRACE and FARRAR [1945 b]), and that only a small additional number of roots are subsequently formed (during the following time) in the present series of experiments. To this we can add that in the second assessments of the series from 1947-48 — that is in 1949 — we often found a smaller number of roots than recorded in 1948, owing to the fact that roots, broken during the first examination and replanted in 1948 had not yet been replaced by new ones.

Thus we can say that within a clonal propagation of Norway spruce and Sitka spruce the length of the cuttings influences the number of roots formed whether they have been cultivated under good or bad environmental conditions, and whether the rooting period has been shorter or longer.

Another question of interest is whether the percentage of rooted cuttings is similar in all sizes of cuttings or not. The figures in Table 7 give us some results which vary from series to series. We are not able to find an absolute correlation between the percentage of rooted cuttings and the size of cuttings, since the reaction of the cuttings here has been greatly influenced by the environmental conditions. Thus the bad external conditions in series n⁰9 (Table 7) have damaged the long cuttings much more than the smaller ones. On the other hand we found in the best series n⁰7 (Table 7), rooted under good environmental conditions, a positive correlation between the two factors. It seems that generally speaking, rooting takes place sooner in the large cuttings than in the small ones, when cultivated under optimal conditions. If not, the smaller cuttings have a better chance to root than the bigger ones owing to the fact that the losses in transpiration weaken the larger cuttings relatively more than the smaller cuttings.

The observed variation in the rooting ability of cuttings of different sizes in the different environmental conditions (expressed by a higher or lower percentage of rooted cuttings in the experiments) occurred also in the results recorded by other workers.

Under good environmental conditions with a good rooting per cent DEUBER and FARRAR (1940) obtained a higher rooting percentage from cuttings 10—20 cm. in length than from cuttings 5—10 cm. long, but they add: "Cuttings that are very long may root poorly, due to a high total transpiration before roots are established". Similar results were found by GRACE and FARRAR (1945), who separated the cuttings into three length classes, 4—7½, 7½—15 and 15—25 cm. They obtained a better rooting percentage in the medium class than in the smaller, but recorded that although the number of roots per rooted cuttings was the highest in the large class, the percentage of rooted cuttings was lower. In contrast to these results RUNQUIST and STEFANSSON (1950) found, in an experiment carried out under unfavourable growth conditions, a reaction of the cuttings similar to that which we obtained in series n⁰9 (Table 7). They separated the material into 2 classes. The length class 5—8½ cm. rooted with 15.4% and the class 10—15 cm. with only 6.6%. The same authors in the following year carried out another experiment under better growth conditions and with a better rooting per cent. Here the cuttings were collected from 8-years-old Norway spruces and separated into three groups, originating from minus, medium or plus plants. All the cuttings were cut to the same length, 7 to 7½ cm., but there was a difference in vigour from the minus to the medium and plus plants. The rooting per cent was 41.0, 58.9 and 71.4 for the three groups respectively. This means that the rooting increased with increasing vigour of the shoots which had been used in the experiment. The relative number of roots in the three groups was 10, 131 and 152.

The formation of new shoots by the cuttings is also influenced by the size of the cuttings. An example is given in Table 9, where the mean figures from the first four collections of the two series of Norway spruce 1944-45 and 1947-48 are recorded. For the other parts of the series we found similar figures. The percentage of cuttings with new shoots also increases with the length of the cuttings. These results seem first of all due to the fact that the number of buds is larger and the development is better in long cuttings than in smaller ones. Under bad environmental conditions when the percentage of dead cuttings is highest among the larger cuttings, the development of new shoots will naturally be also influenced by this factor.

Table 9. — The Influence of the length of cuttings on the formation of new shoots in lateral cuttings of Norway Spruce (the four oldest collections of each series)

Length of cuttings in cm	5-8	9-10	11-12	13-14	15-16	17-18	19-20	Total
Series 1947-48								
Number of cuttings	9	22	12	29	20	2	—	94
„ „ shoots	9	23	18	63	49	7	—	169
„ „ „ per cutting	1.0	1.0	1.5	2.2	2.5	3.5	—	1.8
Series 1944-45								
Number of cuttings	—	—	27	49	33	6		115
„ „ shoots	—	—	70	175	115	25		385
„ „ „ per cutting	—	—	2.6	3.6	3.5	4.2		3.3

Our analysis on cuttings-lengths thus provides the explanation why the figures in Tables 1 and 2 differ somewhat as regards to root- and shoot-developments. The figures in Table 1 are higher than those in Table 2, not only because of differences in environmental conditions in the two series, but primarily because the cutting material of 1944-45 was more vigorous than that of 1947-48; and in addition that different clones were utilized during different years.

Although the size of the cuttings is a very rough expression for the internal rooting potential, and although our studies on the influence of the environmental conditions on rooting have not yet been brought to a final stage, these two groups of factors explain very well most of the observed seasonal variations in the rooting ability of spruce cuttings. Further it seems to me that the influence of the environmental conditions sufficiently explains the differences in rooting capacity recorded by the different authors.

As an example, the two different curves for rooting within the same Sitka spruce, cultivated inside and outside the greenhouses, give us quite opposite results during the summer months and thus the data of DEUBER (1940), originating from greenhouse-cultures can be brought into line with the figures from experiments of GRACE (1946) and of those from the present investigations.

The rest of the seasonal variation in the rooting capacity, observed in the present investigations, may be attributed to the influence of the natural growth substances in the cuttings. In the present research with spruce, we have no experiments on this field; but as the shoots retain their needles throughout the year, it seems natural to think that the growth substances or their precursors can be produced whenever the environmental conditions are favourable.

We must remember that the complex of growth substances not only consists of free and bound, active and inactive growth-promoting auxins but also inhibitors of different kinds, and that the reaction of the plants depends upon the actual balance between these different substances and their precursors (see the review of the literature on formation, occurrence and inactivation of growth substances by LARSEN, 1951). Furthermore it seems that rooting and bud development are controlled by different forms or different concentrations of the growth promoting and growth inhibiting substances.

In our investigations we have also observed that rooting, bud development, and elongation of the shoots occur independently.

Young cuttings collected in June-July produced no new shoots before the following year, but rooted very quickly and to a large extent. In cuttings collected in winter the responses to rooting and shooting differ very much from one sample to another owing to the temperature under which the cuttings have been treated. It seems that a high air temperature accelerates the leafing out and that it is activated more easily on the long cuttings than on the smaller ones (see Figure 4, photos 23 and 24). Also the differences in the rooting response before and after the period of bud development and shoot elongation indicate that rooting and bud development are controlled independently by at least two different factors.

Recent works carried out with several species of plants show not only that dormancy, bud development, flowering, rooting and cambial activity are regulated by the growth substances, but also that these processes can be greatly influenced by altering the environmental conditions. Light especially seems to have a striking effect on most of the processes. For that reason it should be of great interest to examine the influence of this factor on root formation in cuttings.

From the point of view that growth substances represent the primary factor in the seasonal variation of rooting in spruces, we are able to understand why the rooting responses vary so greatly with small differences in the environmental conditions and why the rooting can take place even after a long period of more than a year without any rooting and shoot growth.

Clonal differences in rooting, which have been so striking demonstrated by DEUBER (1940), should then first of all rest in their different capacities to produce and/or activate the growth substances under the prevailing environmental conditions.

At present, experimental proof is lacking for these suggestions and it seems that the spruces are not suitable for this type of experiment owing to the presence of lathering products which complicate or prevent the extraction of the growth substances from the tissues.

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Summary

Clonal series of cuttings from Norway spruce and Sitka spruce, collected in the period from the beginning of June one year to the middle of April next year, and propagated in cold frames, were examined in the following autumn for seasonal variation in natural rooting ability.

A typical seasonal variation in the rooting is assessed. After a very high percentage of rooted cuttings in June-July, the percentage decreases to a minimum in the middle of September. After that date the figures increase during the winter until a new maximum is reached just before leafing out in the middle of April.

This variation is due not to the different length of time elapsing between planting and assessment of the cuttings, but is influenced by the environmental growth conditions as well as by the physiological nature of the cuttings.

Renewed assessments one year later showed such a high percentage of rooting in all parts of the series that the seasonal variation had almost disappeared. It is considered that the clones used should always be able to root to a great extent whenever the collection was made, if cultivated under optimal environmental conditions.

Data concerning the influence of the environmental conditions on the rooting responses are given, as well as an analysis of the influence of the lengths of cuttings on the rooting. These data appear to show that most of the seasonal variation has been caused by variations in the environmental growth conditions and partly also by some variations in cutting length during the year.

It is considered that the remainder of the seasonal variation in rooting is caused by the actual content of growth promoting and growth inhibiting substances in the cuttings, this balance in its turn being influenced by the environmental conditions.

The influence of artificial growth substances on the rooting is not discussed in the present paper.

From a practical point of view the propagation of spruce cuttings under cold frame conditions in Denmark seems to be practicable when planting the cuttings in early spring or in the months of June and July, due to the fact that most of the cuttings are then able to root before the winter.

It is considered that further research on the influence of the environmental conditions on rooting should be very important for the practical propagation of spruce, and that such research would give us further guidance for an optimal treatment of the cuttings with growth substances.

Zusammenfassung

Titel der Arbeit: *Die jahreszeitliche Variation bei der natürlichen Bewurzelungsfähigkeit von Stecklingen der gemeinen Fichte und der Sitkafichte.* —

Serien von Stecklingsklonen von *Picea abies* und *Picea sitchensis,* die in der Zeit von Anfang Juni eines Jahres bis Mitte April des nächsten Jahres gesammelt und in Kaltkästen vermehrt worden waren, sind im darauffolgenden Herbst auf die jahreszeitliche Variation ihrer natürlichen Bewurzelungsfähigkeit hin untersucht worden.

Dabei fand sich eine typische jahreszeitliche Variation in der Bewurzelung. Nach einem sehr hohen Prozentsatz an bewurzelten Stecklingen im Juni-Juli nahm der Prozentsatz bis zu einem Minimum Mitte September ab. Danach stiegen die Zahlen wiederum während des Winters bis zu einem neuen Maximum an, das Mitte April kurz vor dem Austrieb erreicht wird.

Diese Variation wird nicht durch die unterschiedliche Zeitspanne zwischen dem Pflanzen und der Versuchsaufnahme (Auszählung der Stecklinge), sondern allein durch die Wachstumsbedingungen der Umwelt und durch den physiologischen Zustand der Stecklinge beeinflußt. Erneute Befunde bei Versuchswiederholungen im Jahr darauf gaben dann einen derart hohen Prozentsatz an bewurzelten Stecklingen in allen Teilen der Versuchsserien zu erkennen, daß die jahreszeitliche Variation fast nicht mehr wahrnehmbar war. Es wird gefordert, daß die zu verwendenden Klone bei ihrer Sammlung immer in großem Umfang bewurzelungsfähig sein sollten, wenn sie unter optimalen Umweltbedingungen kultiviert werden.

Befunde über den Einfluß der Umweltbedingungen auf die Wurzelbildung werden mitgeteilt, ebenso eine Untersuchung über den Einfluß der Stecklingslängen auf ihre Bewurzelung. Diese Befunde scheinen kenntlich zu machen, daß die meisten jahreszeitlichen Schwankungen durch Variationen in den Wuchsbedingungen der Umwelt und teils auch durch die Schwankung der Stecklingslänge im Verlauf des Jahres verursacht werden.

Es wird geschlossen, daß der Rest an jahreszeitlicher Variation bei der Bewurzelung durch einen wirksamen Gehalt an wachstumsfördernden und wachstumshemmenden Stoffen in den Stecklingen verursacht wird, und dieser Gleichgewichtszustand wird jeweils durch Umweltbedingungen beeinflußt.

Der Einfluß von künstlichen Wuchsstoffen auf die Bewurzelung wird in dieser Arbeit nicht diskutiert.

Vom praktischen Standpunkt aus scheint die Stecklingsvermehrung der Fichte in Kaltkästen für dänische Verhältnisse dann erfolgreich zu sein, wenn das Stecken im frühen Frühjahr oder in den Monaten Juni und Juli geschieht, und zwar im Hinblick darauf, daß dann die meisten Stecklinge noch vor dem folgenden Winter sich bewurzeln können.

Ferner wird die weitere Erforschung der Umwelteinflüsse auf die Bewurzelung vorgeschlagen, die für die praktische Vermehrung der Fichte von Wichtigkeit sein dürfte, und es wird betont, daß solche Untersuchungen weitere Hinweise für eine optimale Stecklingsbehandlung mit Wuchsstoffen liefern könnten.

Résumé

Titre de l'article: *Variation saisonnière des possibilités naturelles d'enracinement des boutures de Picea abies et Picea sitchensis.* —

Des séries de boutures de *P. abies* et *P. sitchensis,* représentant chacune un clone, furent récoltées du début juin d'une année jusqu'à la mi-avril de l'année suivante, et multipliées dans des couches froides; les rélultats furent analysés à l'automne suivant, dans le but de déceler une variation possible dans la capacité d'enracinement.

On trouva une variation saisonnière très nette. Après un très fort pourcentage de boutures enracinées en juin-juillet, ce pourcentage diminue pour atteindre un minimum en mi-septembre. Il augmente de nouveau pendant l'hiver jusqu'à un nouveau maximum en mi-avril, peu avant le débourrage.

Cette variation n'est pas influencée par la longueur de l'expérience (temps écoulé depuis la mise en place jusqu'au dénombrement des boutures racinées); elle dépend uniquement des conditions du milieu et de l'état physiologique des boutures. De nouveaux comptages effectués l'année suivante révélèrent un très haut pourcentage de boutures enracinées dans toutes les séries, à tel point que la variation saisonnière n'était presque plus perceptible. On considère que les clones employés ont une grande capacité d'enracinement, quelle que soit la date de la récolte, pourvu qu'ils soient cultivés dans des conditions de milieu optimales.

On donne les résultats concernant l'influence des conditions du milieu sur la production des racines, ainsi qu'une analyse de l'influence de la longueur des boutures sur leur capacité l'enracinement. Il semble que ces résultats démontrent que plupart des fluctuations saisonnières sont causées par les variations des conditions d'accroissement sous l'influence du milieu et aussi par la variation de la longueur des boutures au cours de l'année.

On conclut que le reste de la variation saisonnière pour l'enracinement est en relation avec la quantité de substances stimulant ou inhibant l'accroissement, contenue dans les boutures; cet état d'équilibre est à son tour influencé par les conditions du milieu.

L'influence des substances de croissance synthétiques sur la production des racines n'est pas discutée dans cet article.

D'un point de vue pratique, la production de boutures d'épicéa en couche froide semble avoir un intérêt sous le climat du Danemark si le bouturage est exécuté au début du printemps, ou bien en juin ou juillet, parce que dans ce cas la plupart des boutures peuvent s'enraciner avant l'hiver.

On pense que de nouvelles recherches concernant l'influence du milieu sur la production des racines, auraient un grand intérêt pour la multiplication de l'épicéa dans la pratique; de telles recherches donneraient de nouvelles indications pour le meilleur traitement des boutures par les substances de croissance.

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