United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

Research Paper NC-278

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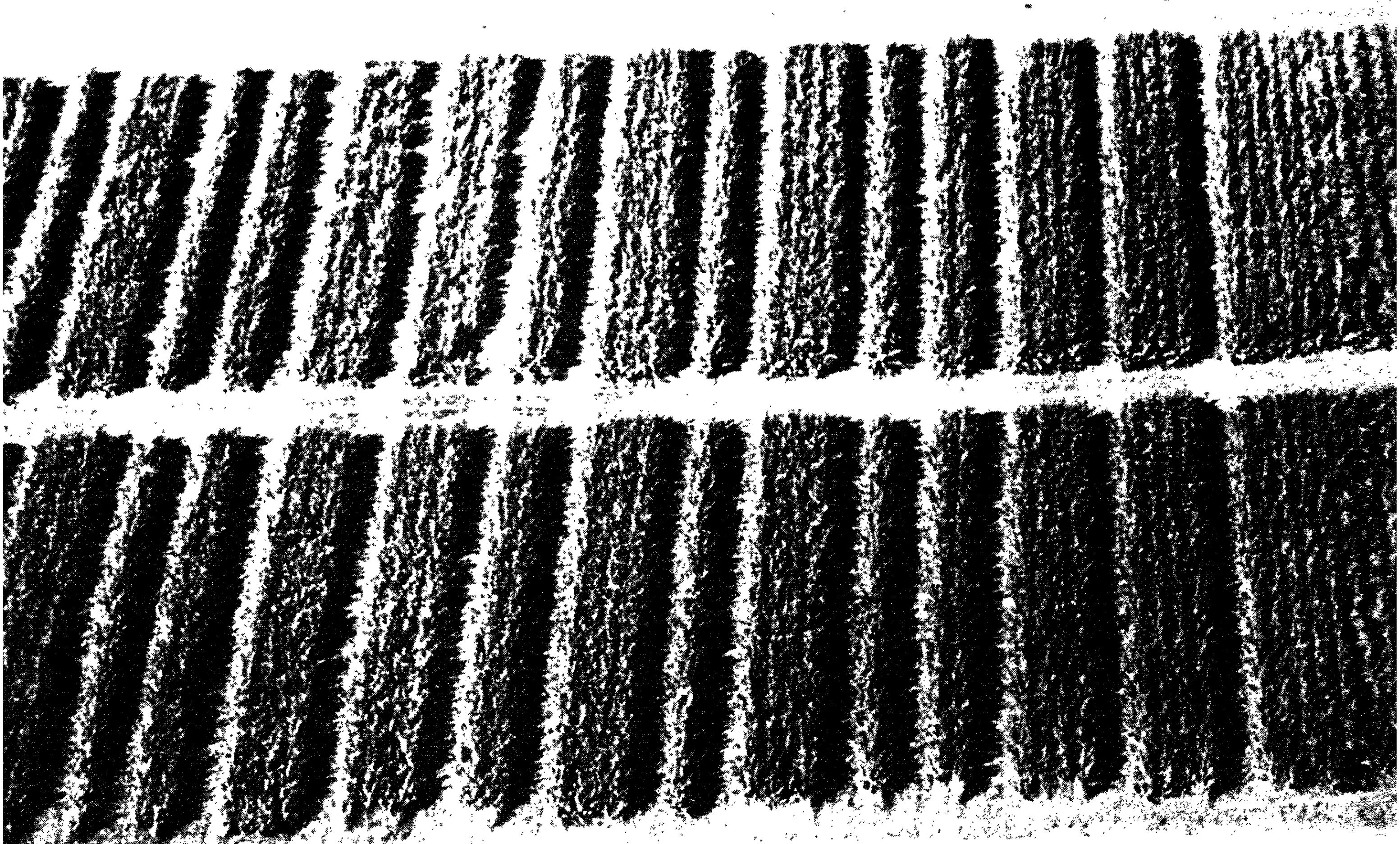
Edward A. Hansen and Daniel A. Netzer



North Central Forest Experiment Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication August 29, 1986
1986

HYBRID POPLAR STOOL SPACING: EFFECTS ON HARDWOOD CUTTING PRODUCTION

Edward A. Hansen, *Research Forester,*
and **Daniel A. Netzer**, *Forester,*
Rhinelander, Wisconsin

Hybrid poplar plantations are established with either rooted or unrooted hardwood cuttings (Hansen *et al.* 1983, Dickmann and Stuart 1983). Because in some cases tree spacing may be as little as 1 by 1 m (or closer), as many as 10,000 cuttings/ha may be required. Whether these high density plantings or more traditional spacings of 3 by 3 m are used, substantial nursery acreage is required to produce cuttings. It is in the interest of the nursery manager to maximize productivity of the nursery and to produce high quality cuttings. Hybrid poplar nurseries (also called clonal orchards or cutting orchards) consist of poplar stumps (stools) from which stump sprouts are harvested annually (see Fege and Phipps (1984) for discussion on effect of harvest time on cutting quality). The 1-year-old sprouts are then cut into shorter lengths (cuttings). Stool spacing and age are generally thought to affect production, but little specific information is known about this.

We investigated the effect of stool age and spacing on stool mortality, cutting production per stool, and cutting production per unit of land area for three hybrid clones. Next we investigated cutting quality as affected by stool spacing. Larger diameter cuttings are known to produce taller shoots the first year following planting (Dickmann *et al.* 1980). If closer stool spacing produces smaller cuttings, quality would be reduced. Therefore, we investigated the cutting size produced by different stool spacings. As an indicator we compared the median (50 percent) cutting diameter obtained from each stool spacing. Cutting position has some effect on cutting quality (Hansen and Tolsted 1981). Because stool spacing could affect cutting size at a given stem position, we also compared the median cutting size from the fourth cutting position above the base for all stool spacings as a more sensitive test of cutting quality. Finally, we planted and observed first-year growth of sets of cuttings randomly selected from all cuttings and also from fourth position cuttings for each clone-spacing-replication combination. From these data we were able to determine the effect of stool spacing on stool mortality, cutting production, cutting size, and subsequent cutting survival and growth.

METHODS

The clonal orchard site was at Harshaw Forest Research Farm near Rhinelander, Wisconsin. The Padus silt-loam soil was plowed, disced, and harrowed in the fall. Linuron was applied at 1.1 kg active ingredient per ha prior to planting in the spring. Hardwood cuttings were prerooted in bookplanters and transplanted into the field in mid-June. Three of our fastest-growing clones, based on 10 years of clonal trial data, were selected. The clonal numbers and parentages were NE-1 (*Populus nigra* × *P. laurifolia*), NE-386 (*P. candicans* × *P. berolinensis*), and NE-387 (*P. candicans* × *P. berolinensis*). The area was fertilized in June of each year with ammonium nitrate nitrogen through the irrigation system at the rate of 112 kg/ha. Irrigation water was applied as necessary to maintain soil moisture tension at less than -0.7 bar (-7×10^5 Pa) as determined from a network of tensiometers. Reinvading weeds were controlled as required by broadcast spraying Roundup at 1.6 kg active ingredient per ha between the stool beds in early May each year. Cuttings of each clone were planted in 40-m-long rows in groups of one, two, and four rows with four replications. Spacing was 3.7 m between groups and 1 m between rows within the two- and four-row groups. Stool spacing within rows was 1 m except in a second set of four-row groups where a 0.5 m stool spacing was used. Area per stool ranged from 0.5 by 1 m in the interior two rows of the closest spaced four-row group to 1 by 3.7 m in the single row (table 1).

Table 1.—*Stool spacing and area per stool used in study*

Number of rows	Within row	Between row	Spacing area/stool
	·········m·········		··m^2··
1	1	3.7	3.7
2	1	1 & 3.7	2.3
4	1	1	1.0
4	.5	1	.5

After the second growing season, the trees were cut at a 15-cm height each winter. The percent of live stools were inventoried in each combination of clone, row group and replication. A systematically located sample consisting of a block of five live stools was harvested each year to assess cutting production and size. The harvested shoots were kept separate by stool, cut into 20-cm long cuttings, and all cuttings with a diameter smaller than 7 mm were discarded. The remaining cuttings were counted and recorded as "total cuttings per stool". During the second and third harvest years, the diameter of the small end of the cuttings was measured for all cuttings from one randomly selected stool from each block of five stools. These data were used to construct a frequency distribution of cutting diameters for each clone-spacing combination.

During the third harvest year (4-year-old stools), the fourth cutting above the shoot base was kept separate from the other cuttings. All fourth cuttings from a block of five stools were pooled into one set and all cuttings from the remaining positions were pooled into a separate set. Therefore, we had two sets of cuttings for each clone-spacing-replication combination. A subsample of 15 cuttings was selected from each set of fourth cuttings. The remaining fourth cuttings were pooled with the set containing cuttings from all other positions and a 30-cutting subsample selected. These subsamples were selected so that they encompassed the range of cutting diameters. They were then planted the following spring in a replicated randomized block design to test for quality differences in cuttings grown under different stool spacings. Cuttings from replication one in the stool-spacing study comprised the material in replication one of the cutting quality study, etc. The cuttings from the main cutting population and from the fourth position were planted at 0.3 by 0.3 m spacing in separate but contiguous blocks. Survival and total height were measured at the end of the first growing season.

Effects of stool spacing were analyzed by ANOVA ($P = 0.05$) using the following five measures from the cuttings after their first year of growth in the field: (1) mean height growth of the 30 planted cuttings, (2) calculated height growth of the cutting of median diameter of the 30 cuttings, (3) calculated mean height growth of the cutting population from which the 30-cutting sample had been selected, (4) mean height growth of the 15 fourth cuttings, and (5) calculated height growth of the cutting of median diameter of the 15 fourth cuttings. The calculated height growth of the median diameter cutting and of the "cutting population" (2, 3, and 5 above) were used in case either of the subsamples had a biased distribution of diameters that affected measured mean height. The second factor above was calculated by developing a regression equation first between cutting diameter and height growth for the set of 30 cuttings and then from the regression calculating the height corresponding to the median diameter. The third factor was obtained using the same regression by first calculating the height corresponding to each 1 mm diameter class (for 7 mm and above), weighting the calculated height by the actual number of cuttings of the same diameter produced by four stools in that class, summing all diameter classes, and dividing by the total number of cuttings produced by the four stools in that clone-spacing combination. This calculated value is an unbiased estimate of the average height that would have been obtained if all cuttings had been planted. The fifth factor was calculated similarly to the second factor except that data from the set of 15 cuttings from the fourth cutting position were used.

RESULTS

Stool Survival

Survival was 100 percent for all clones and stool spacings through the second harvest season (3-year-old stools). Thereafter, stool survival decreased with age and closer stool spacing for all three clones (table 2). Although 5-year-old stool survival decreased only slightly from 99 to an average of 94 percent over increasing stool spacing from 3.7 m^2 to 1 m^2, it decreased significantly down to an average of 77 percent when stool spacing decreased to 0.5 m^2. The data indicate that if these three clones are planted at a 0.5 by 1 m spacing, they self-thin from competition even under good cultural conditions.

Table 2.—*Percent stool survival as related to spacing for 4- and 5-year-old stools (survival was 100 percent for all spacings with 3-year-old stools)*
(In percent)

Spacing	4-year-old stools				5-year-old stools			
m^2/stool	NE-386	NE-1	NE-387	Ave.	NE-386	NE-1	NE-387	Ave.
3.7	98	99	100	99	99	98	99	99
2.3	98	99	100	99	94	94	98	96
1.0	97	98	100	98	92	92	96	94
0.5	88	94	97	93	73	73	84	77

Cutting Production

Cutting production per stool differed significantly with stool spacing, ranging from 18 per stool for clone NE-386 at a 0.5 m^2 spacing to 124 per stool for clones NE-1 and NE-387 at a spacing of 3.7 m^2. Cutting production per stool was highest at the greatest stool spacing and declined with decreasing stool spacing (table 3).

Cutting production per m^2 was calculated from stool production and spacing data and then adjusted for stool mortality. The results show that cutting production per stool generally declined as stool spacing decreased. However, lower cutting production per stool was more than compensated for by greater stool numbers, so that cutting production per unit land area was greatest with the closer stool spacings (table 3). Although the closest spacing resulted in significantly greater cutting production per unit land area, variation by clone was considerable. In several cases during the 3 years that cutting production was measured, production was similar whether stool area was 0.5 or 1 m^2. Furthermore, it was not always the same clone that responded that way. It appears that higher production would usually be obtained with the closest spacing tested, but it is not entirely consistent for either clone or year.

Table 3.—*Number of cuttings produced as related to stool spacing for 5-year-old stools*
(In number)

Spacing m^2/stool	NE-386	NE-1	NE-387	Ave.
	CUTTINGS/STOOL			
3.7	103	124	124	117
2.3	79	82	92	84
1.0	41	60	67	56
0.5	53	51	34	46
	CUTTINGS/m^2			
3.7	27	33	34	31
2.3	32	34	34	33
1.0	38	58	66	54
0.5	78	86	67	77

Cutting production from stools age 3 through 5 years varied greatly from year to year. We attribute this primarily to fluctuations in summer climate. For example, production at the closest spacing (0.5 m^2) averaged 83, 40, and 77 cuttings/m^2 for the third through fifth harvest years, respectively.

Cutting Diameter

We found no evidence that stool spacing affected median cutting diameter of cuttings greater than 7 mm in diameter. There was only a small range in median diameter and no consistent trend with stool spacing (table 4). These observations are consistent for all clones and for both the "all cutting" and the "fourth cutting" sets. The maximum difference in median cutting diameter between different stool spacings for one clone was only 1.4 mm. In most cases the differences were much less. Because these data were based on a sample size of 5 stools for each treatment combination, we quadrupled the sample size to 20 stools for clone NE-387 to check whether a trend in median diameter was being obscured by insufficient sample size. A test of this larger sample size still resulted in no significant relation between stool spacing and cutting diameter. Furthermore, the larger sample size did not change the ranking of median diameter by stool spacing, and median diameter for any specific stool spacing changed less than 0.2 mm. We concluded that a five stool sample size was sufficient for this test.

The largest cutting diameters tended to come from stools in single and double rows. However, the stools

Table 4.—*Median cutting diameter as related to stool spacing for 4-year-old stools*
(In mm)

Spacing	All cuttings				4th cutting position			
m^2/stool	NE-386	NE-1	NE-387	Ave.	NE-386	NE-1	NE-387	Ave.
3.7	8.9	8.8	8.9	8.87	8.1	8.6	9.0	8.57
2.3	8.8	8.8	9.0	8.87	8.7	8.0	9.0	8.57
1.0	8.4	9.4	9.2	9.00	7.8	9.4	8.8	8.67
0.5	8.9	8.4	8.7	8.67	8.7	8.1	7.9	8.23
				8.85				8.51

at these wider spacings produced more cuttings of all sizes so that median diameter did not change.

Cutting Survival

Little evidence was found that stool spacing had any influence on cutting survival during the first year of field growth. Overall survival averaged 92 percent. Mortality showed no trend with stool spacing for any of the clones, except clone NE-386 (table 5). That clone had unusually high mortality in replication one of the "all cutting" test where mortality increased to 77 percent at the closest stool spacing. We observed that water frequently ponded in replication one. Cutting quality of that clone may have been expressed by the adverse conditions whereas the other clones may have been tolerant to those conditions. However, this experimental design did not allow testing that hypothesis.

Cutting Growth

Average tree height at the end of the first growing season was 165 mm (table 6). Mean height differed little for the three computation methods indicating that the 30-cutting sample was an unbiased sample of the entire cutting population. Stool spacing had no significant effect on cutting height growth regardless of the height measurement used. Also, height growth showed no consistent trend with the stool spacing that the cutting had been grown under. Height variation across stool spacings within any particular clone was a maximum of 22 mm but was usually less than 10 mm as compared to the total height growth of 165 mm. Consequently, even if this height variation were related to stool spacing, it would not be very important. But the lack of significance and the fact that the two tallest treatments were from the extremes in stool spacing eliminates stool spacing as a factor in subsequent cutting growth. The results of the test for the fourth cutting position (data not shown) were similar to these from the 30-cutting sample.

DISCUSSION

Nursery operations normally involve intensive management. Therefore, it is desirable to maximize production per unit land area so as to minimize land area and hence costs. This study shows that hardwood cutting production for the three hybrid poplar clones tested is greatest with a stool spacing of 0.5 by 1 m (the closest spacing tested). However, production was sometimes nearly as great with only half the stool density (1 by 1 m). The measured production from 5-year-old stools at the two closest stool spacings would produce yields ranging from 380,000 to 860,000 cuttings/ha (154,000 to 348,000 cuttings/acre).

Table 5.—*Number of dead cuttings as related to stool spacing after one growing season in the field*

	All cuttings				4th cutting position		
Spacing	NE-386		NE-1	NE-387	NE-386	NE-1	NE-387
m^2/stool	no. dead/120 cuttings				no. dead/60 cuttings		
3.7	2[1]	7	6	5	5	7	1
2.3	17	23	8	5	3	3	0
1.0	17	25	5	3	4	3	0
0.5	23	37	9	5	3	3	0

[1]Column shows mortality in replication 1.

Table 6.—*Height growth of the cuttings as related to stool spacings after one growing season in the field (three different measures of height growth are derived from the 30-cutting sample)*
(In mm)

Spacing m^2/stool	NE-386	NE-1	NE-387	Ave.
MEASURED HEIGHT				
3.7	171	176	169	172
2.3	159	166	164	163
1.0	152	165	165	161
0.5	165	174	162	167
Ave.	162	170	165	166
CALCULATED HEIGHT OF MEDIAN DIAMETER CUTTING				
3.7	168	172	165	168
2.3	155	164	163	161
1.0	146	166	163	158
0.5	163	172	160	165
Ave.	158	168	163	163
CALCULATED AVERAGE HEIGHT OF ALL CUTTINGS				
3.7	167	171	168	169
2.3	156	166	162	161
1.0	147	166	163	159
0.5	164	172	158	165
Ave.	158	169	163	164

If cuttings were limited and it were desirable to produce the maximum number of cuttings from limited planting stock, the cuttings (stools) should be planted far apart. In this study the widest spacing (1 by 3.7 m) had significantly greater cutting production per stool than the next closest spacing (1 by 2.3 m).

Stool spacing in a hybrid poplar clonal orchard had no effect on the quality of cuttings produced. Neither cutting diameters nor the ability of the cuttings to survive and grow when planted were affected. However, it is possible that quality differences might show up under more adverse planting site conditions. The lack of statistical significance; the absence of any trend; and the small range in data for cutting diameter, survival, or growth with stool spacing eliminates cutting quality from consideration when determining stool spacing in nurseries.

It is concluded that stool spacing of 1 by 1 m or closer for the hybrid poplar clones tested will maximize hardwood cutting production per unit land area and will not affect diameter or quality of hardwood cuttings. Other clones or growing conditions may change these relations, so the optimum spacing to maximize cutting production per stool or per unit land area may differ from those reported here.

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Hybrid poplar stool spacing: effects on hardwood cutting production. Res. Pap. NC-278. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 5 p.

Stool spacing of 1 by 1 m and closer maximized hardwood cutting production per unit land area. Stool spacing did not affect diameter or quality of hardwood cuttings.

KEY WORDS: Forest nurseries, clonal orchards, cutting orchards, intensive culture, short rotation, Populus.