in J.P. Barnett, ed. Proc. First Biennial South. Silvicultural Research Conf., Atlanta, GA. USDA For. Serv. Gen. Tech. Rpt. SO-34, pp. 131-136. 1981.

A THINNING RULE FOR SLASH PINE PLANTATIONS ON A MEDIUM SITE[1/]

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Abstract.--Target, after-thinning, residual densities that produce near maximum periodic growth of slash pine plantations are determined for medium sites with an average height at age 25 of 63 feet. This was done by fitting net 5-year growth (in pounds of dry wood per acre) to the corresponding values of Stahelin's percent stocking obtained from unthinned stands covering a wide range of densities. This approach is based on the assumption that the growth of the thinned stand will quickly recover to that of an unthinned stand of the same percent stocking. The stand ages at which thinnings should be made were also established. This age is defined as the point where the annual accretion of what would be the yield from a first thinning begins to decrease.

INTRODUCTION

Growing space is a leading factor in controlling the growth rate of individual trees. The choice of planting spacing and the timing and intensity of thinning offers foresters who manage slash pine plantations two methods of controlling this determinant of tree growth. Much has been published about the effects of the planting spacing on yield, but very little on the interrelationship between initial spacing and subsequent thinning schedules.

A defendable strategy for pulpwood production is to maximize total net growth (i.e., growth of surviving trees minus mortality) from a site over the rotation. This is accomplished by thinning as frequently as is economically possible in such a way as to salvage potential mortality and maintain the stand at near full occupation of the site. The problem is that measurement of net growth is both costly and subject to large error. What we do then is calibrate more easily observed or measured stocking attributes with net growth and use the stocking measure as the control variable. Stahelin's (1949) stocking percent is used in this study because it is easily obtained by using an angle prism, does not depend on age and site quality, and has been successfully applied to thinned stands of natural slash pine (Gruschow and Evans 1959). The goals of this work are 1) to estimate target residual densities and ages of the first thinnings for plantations resulting from a wide range of planting densities on a medium slash site and 2) to hypothesize stocking guides as to when to initiate first thinnings in these slash pine plantations.

SOURCE OF DATA

These data come from a study established by the Southeastern Forest Experiment Station in 1952 on the Holt Walton Experimental Forest in the middle Coastal Plain region of Georgia. Seedlings were planted at 8 spacings: 15 x 15, 7.5 x 15, 10 x 10, 6 x 12, 8 x 8, 5 x 10, 6 x 8, and 6 x 6 feet. Three-quarter-acre spacing plots were randomly assigned in each of two complete blocks, and the entire study was installed in an old field which had last been cultivated the previous year. Harms and Collins (1965) observed that with good soil moisture conditions and care in handling and planting the seedlings, 97 percent survival at age 4 resulted--much better than average, with each spacing plot as fully stocked as could be expected. Starting at age 10, measurements for each plot consisted of a complete diameter tally and a random sample of heights on at least 20 trees distributed evenly over the diameter classes. These measurements were taken annually from age 10 through age 22 and again at age 25.

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PROCEDURES

The diameter and height measurements on the two plots for each spacing were combined into a composite plot and converted to yield (in pounds) of total stem dry weight (i.b.) per acre (Queen and Pienaar 1977). Weight was used instead of volume because we wanted total yield to a 2-inch diameter class and a volume table for this range of diameters was not available when the analysis started, and because the use of pulpwood weight is extensive. These computations resulted in 112 stand tables and yield observations (eight spacings each measured 14 times). Each spacing yielded nine 5-year net growth values for the growth periods 10 to 15, 11 to 16,..., 17 to 22, and 20 to 25 years. We chose the 5-year growth period because it represents the practical minimum time between thinnings. Also, the coefficient of variation for growth becomes prohibitively large for periods shorter than five years. The first step was to relate these increments of net periodic growth to some measure of stocking.

Gruschow and Evans (1959) successfully used Stahelin's (1949) percent stocking as a predictor of periodic growth of thinned natural stands of slash pine. They chose not to use basal area alone because at theoretical full stocking it varies widely with site and age. In addition, because of our range of 1000 seedling per acre at planting, we wanted a stocking measure that reflected increasing basal area for the same stocking level as the number of trees per acre decreased. Figure 1 illustrates how these data approach and then follow Stahelin's 100 percent curve for the two densest spacings.

The decision of when to thin depends on the target stocking because a greater percentage of volume is removed to obtain the lower residual densities. Therefore, the first step in this analysis concerned establishing a range for residual stocking that produced near maximum periodic growth. This was done by combining the data from all spacings and then studying the relation of 5-year net growth to Stahelin's (1949) percent stocking. This is based on the assumption that periodic growth of a thinned stand will be close to that of an unthinned stand with the same percent stocking. A point of maximum growth was expected to be contained in these data because of the wide range of planting densities.

The stand age at the first thinning from below varies with planting spacing and, as discussed earlier, probably with the target residual stocking. We estimated this stand age as that point in stand development where the annual increase in the weight of the first thinning begins to decline. We approximated the yields for the first thinning at each age by removing trees one at a time from the observed stand tables until the target residual density was reached. The onset of declining thinning yield is estimated as the point of inflection for a model expressing the above defined thinning yield as a function of stand age. These removed yields are only approximations to real thinnings because diameter distributions do not contain information about spacial distributions of the residual stands, but because we are removing the smallest trees, the outcome of actual thinnings should not differ greatly.

For a given planting spacing, the age of maximum accretion in the first thinning yield will increase with decreasing plantation survival, so although these ages can be used to compare the timing of the first thinning under the uniform conditions of this study, they do not offer useful guidelines for field applications. However, if either percent stocking or basal area values corresponding to these ages are stable, then a general thinning rule is suggested. This is our approach to satisfying the second objective.

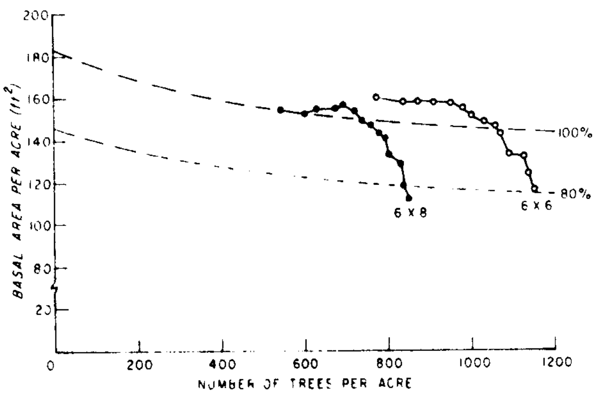

Figure 1.--The basal area and number of trees per acre for the 6 x 8 and 6 x 6 spacings plotted with Stahelin's 100 and 80 percent stocking curves.

RESULTS

The nine periodic growth and percent stocking values were combined for the eight spacings (72 observations) and plotted (fig. 2, see last page). The mean relationship was adequately described with the quadratic equation: periodic growth = 5332.47 + 833.556 (% stocking) - 6.86355 (% stocking)^2. The R^2 value of the model is 0.44. The large variation is explained in part by the inherent variability in growth due to measurement error, as well as variation resulting from the spacing plots. Maximum net growth from this equation occurs at 60 percent stocking which (as was anticipated) is inside the observed stocking range. The following predictions from this equation (rounded to the nearest 100 lbs.)

illustrate the declining rate of periodic growth for stocking above 80 percent:

Percent stocking	Lbs/acre
40	27,700
50	29,900
60	30,600
70	30,000
80	28,100
90	24,800
100	20,100
110	14,000

Gruschow and Evans observed that the rate of increase for percent stocking was low in the lightly and heavily stocked stands and tended to be greatest at the 40 to 50 percent levels. This observation was substantiated by our data, so residual levels of 60 percent, 50 percent, and 40 percent stocking were used to investigate the question of when to thin. As with Gruschow and Evans' work with natural slash pine, we expect the percent stocking levels for maximum growth to be higher for plantations on better sites, but were unable to investigate site effects in this study.

The estimated ages of thinning for these plots are shown in table 1 for residual stockings of 60, 50, and 40 percent. The growth rate of thinning yield culminates before age 10 for the two densest spacings. The effect of planting spacing on age of first thinning is large, while the effect of residual stocking on thinning age is only a 1-year reduction for each 10 percent reduction in residual stocking. The residual basal areas are not constant, but range from 10 to 15 ft.^{2} across the initial spacing range. This outcome fits Reineke's (1933) result which shows basal area for a given stocking level to be proportional to the inverse of number of trees per acre. The standing basal areas and corresponding percent stockings at the predicted thinning ages for residual stockings of 60, 50, and 40 percent are shown in table 2. The average standing basal area values suggest to thin to 60, 50, and 40 percent stocking when basal area reaches 119, 112, and 107 ft.^{2}, respectively.

We have included raw data in table 3 for the person interested in viewing the analysis from other angles. The problem of extreme variation in annual growth is clear if yearly differences are computed, for by using these differences it is difficult to determine with any degree of certainty the optimum thinning age as defined. However, cubic functions of time using all thinning yields for a given spacing and residual percent stocking have R^2's greater than 0.99, and therefore give precise estimates of average net growth for any age in the observed age range and good estimates of the point of inflection. The sums (i.e., total yields) of the pairs of numbers for each age and planting spacing is the same (within rounding error) for all residual percent stockings, but the thinning component accounts for a larger percent of the total as residual stocking decreases. The magnitude of thinnings in table 3 also gives information about the economic feasibility of first thinnings at various ages.

Table 1.--Estimated age for thinning in eight planting spacings to achieve three selected residual stock densities expressed as Stahelin's percent stocking

Planting spacing	Thinning age	Trees per acre at thinning	Basal area after thinning	Trees after thinning
ft	yr	no	ft^2	no
RESIDUAL DENSITY: 60 PERCENT STOCKING				
15 x 15 1/	>25	<161	>101	
7.5 x 15	19	339	97	240
10 x 10	17	367	96	269
6 x 12	16	507	94	343
8 x 8	13	642	92	421
5 x 10	12	819	90	538
6 x 8 1/	<10	>850	<90	
6 x 6 1/	<10	>1152	<87	
RESIDUAL DENSITY: 50 PERCENT STOCKING				
15 x 15 2/	21	165	84	128
7.5 x 15	17	347	81	217
10 x 10	16	374	80	223
6 x 12	14	520	78	303
8 x 8	12	651	77	366
5 x 10	11	826	75	482
6 x 8	<10	>850	<75	
6 x 6	<10	>1152	<72	
RESIDUAL DENSITY: 40 PERCENT STOCKING				
15 x 15 2/	21	165	67	97
7.5 x 15	16	349	64	173
10 x 10	15	376	64	182
6 x 12	13	523	63	250
8 x 8	11	652	61	302
5 x 10	11	826	60	372
6 x 8	<10	>850	<60	
6 x 6	<10	>1152	<58	

1/Annual growth rate in thinning yield culminates outside the observed age range (10 to 25 years).
2/Values supported by limited number of data points.

Table 2.--The age, basal area, and percent stocking before thinning for five planting spacings to be thinned to residual densities of 60, 50, and 40 percent stocking

Planting spacing[1/] (ft)	Residual Percent Stocking								
	60			50			40		
	Thinning age	Basal area	Stocking	Thinning age	Basal area	Stocking	Thinning age	Basal area	Stocking
	yr	ft^2	percent	yr	ft^2	percent	yr	ft^2	percent
7.5 x 15	19	118.9	74	17	109.5	68	16	105.1	65
10 x 10	17	117.7	73	16	114.7	72	15	109.1	68
6 x 12	16	119.3	76	14	112.4	72	13	105.9	68
8 x 8	13	120.1	78	12	114.1	74	11	104.3	68
5 x 10	12	119.3	79	11	110.6	74	11	110.6	74
Mean		119	76		112	72		107	69

1/The 15 x 15, 6 x 8, and 6 x 6 spacings are not included because maximum annual growth rate in thinning yield occurs outside observed age range of 10 to 25 years.

CONCLUSIONS

Maximum periodic growth in total stem wood (i.b.) on average slash pine sites (63 feet, base age 25) is maintained by thinning when basal area reaches 119, 112, and 107 ft.^{2} for residual stockings of 60, 50, and 40 percent, respectively. These guides should apply for several subsequent thinnings, but we are not able to test this assertion with these data. The choice of residual stocking will depend on how frequent subsequent thinnings will be made and how much is needed to be economically feasible. The 40-percent residual stocking leaves a light basal area, but the net periodic growth following this intensity of thinning is 90-percent of the maximum and the growth is increasing. Another point illustrated by these data is that target residual basal area is not constant but, rather, increases as the residual number of trees decreases. As expected, the age at time of thinning decreases as planting density increases, but will vary with plantation survival, so the decision when to thin should be determined by periodically checking standing basal area.

LITERATURE CITED

Gruschow, G. F., and T. C. Evans.
1959. The relation of cubic-foot volume growth to stand density in young slash pine stands. For. Sci. 5:49-55.

Harms, William R., and Arthur B. Collins III.
1965. Spacing and twelve-year growth of slash pine. J. For. 63:909-912.

Queen, William R., and Leon V. Pienaar.
1977. Green and dry stem weight equations for site-prepared slash pine plantations in the Coastal Plain of Georgia and North Florida. Univ. Ga., Schl. For. Resour. Res. Pap. 1, 58 p. Athens.

Reineke, L. H.
1933. Perfecting a stand-density index for even-aged forests. J. Agric. Res. 46:627-638.

Stahelin, R.
1949. Thinning even-aged loblolly and slash pine stands to specified densities. J. For. 47: 538-540.

Table 3.--Weight of yield removed in thinning (lower value) and left in residual stand (upper value) for theoretical thinnings applied at ages 10 through 22 and age 25, in eight spacings reduced to residual densities of 60, 50, and 40 percent stocking

100 pounds

RESIDUAL DENSITY: 60 PERCENT STOCKING

Age (years)	Planting spacing (feet)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
10	147	247	264	300	304	291	307	291
	0	0	0	0	6	39	70	85
11	182	289	312	329	323	324	325	314
	0	0	0	0	35	63	98	118
12	237	373	387	387	369	358[1]	368	347
	0	0	0	35	83	102	150	163
13	272	411	438	417	402[1]	382	401	350
	0	0	7	47	110	119	177	170
14	343	497	491	459	459	424	448	408
	0	6	38	79	153	155	223	233
15	380	533	533	499	499	460	472	437
	0	29	62	103	182	176	249	256
16	430	569	567	514[1]	519	486	498	455
	0	41	99	120	213	209	272	277
17	470	593	586[1]	534	537	496	516	474
	0	66	115	137	234	222	284	298
18	543	637	619	562	561	534	545	508
	0	99	159	180	289	269	332	338
19	609	668[1]	661	607	594	565	580	519
	0	131	186	209	315	289	358	362
20	665	695	689	623	619	588	614	549
	0	154	227	216	337	303	371	375
21	702	714	711	647	654	612	643	571
	0	179	254	237	361	313	373	377
22	741	734	737	649	671	633	657	589
	0	200	248	250	343	297	373	388
25	830	792	785	728	736	683	715	624
	73	264	310	289	377	330	404	406

100 pounds

RESIDUAL DENSITY: 50 PERCENT STOCKING

Age (years)	Planting spacing (feet)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
10	147	247	264	271	257	245	258	248
	0	0	0	29	53	85	119	128
11	182	289	297	280	273	272[1]	273	264
	0	0	15	48	85	115	150	167
12	237	351	338	327	309[1]	302	310	291
	0	22	48	95	144	158	208	218
13	272	368	372	352	337	321	335	294
	0	43	73	112	175	179	243	226
14	343	422	413	385[1]	386	358	375	344
	0	81	116	153	226	221	296	297
15	380	449	447	422	421	385	396	369
	0	112	148	181	260	251	324	325
16	430	478	476[1]	433	438	407	419	385
	0	131	189	201	294	288	351	347
17	470	498[1]	495	448	454	417	435	399
	0	160	206	223	318	301	365	372
18	535	538	518	471	469	449	462	425
	8	198	260	271	380	353	415	421
19	572	563	554	510	496	476	485	437
	37	237	292	307	412	378	452	444
20	593	584	581	525	520	498	515	462
	71	265	336	314	436	393	470	463
21	617	600	599	544	551	517	540	480
	85	292	365	340	464	408	476	468
22	642	618	621	542	566	534	552	497
	99	316	365	357	448	395	479	480
25	701	668	657	610	617	577	605	530
	202	387	437	407	496	435	514	501

Table 3.--Continued

Age (years)	Planting spacing (feet)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
	100 pounds							
	RESIDUAL DENSITY: 40 PERCENT STOCKING							
10	147	227	226	221	207	196	207	203
	0	20	39	79	103	133	170	172
11	182	242	240	228	224 1/	220 1/	221	212
	0	47	72	101	134	167	202	219
12	237	285	275	262	247	246	250	234
	0	88	112	160	206	214	269	275
13	272	297	300	286 1/	271	259	270	238
	0	114	145	179	241	241	308	282
14	332	341	330	312	311	287	303	279
	11	162	198	226	301	292	369	361
15	364	363	361 1/	341	341	310	320	300
	16	198	234	262	339	326	401	394
16	387	388 1/	385	349	352	328	340	309
	43	221	281	285	380	367	430	423
17	409	402	398	361	364	337	354	321
	61	256	303	311	408	381	447	450
18	438	432	419	380	377	365	372	342
	105	304	359	362	472	437	506	504
19	466	456	448	413	400	385	391	352
	143	343	398	404	509	470	547	529
20	481	472	468	424	422	402	414	374
	184	377	449	415	534	489	570	551
21	501	482	482	438	446	416	439	389
	201	411	482	446	569	509	577	559
22	518	496	502	436	459	431	448	406
	223	438	484	464	555	498	582	572
25	566	540	533	494	499	469	487	426
	337	515	561	523	614	543	632	605

1/Culmination of annual growth in thinning yield.

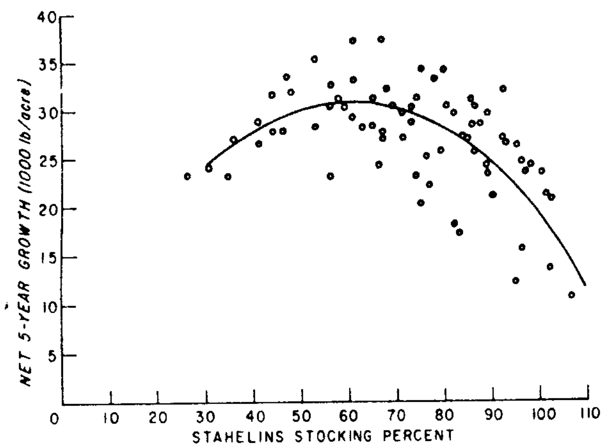

Figure 2.--Net 5-year growth in pounds for total stem dry weight and percent stocking points with the fitted quadratic function used to estimate the stocking level with maximum growth.