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JOURNAL OF AGRICULTURAL RESEARCH

VOL. 73 WASHINGTON, D. C., AUGUST 15, 1946 No. 4

TESTS OF DIRECT SEEDING WITH PINES IN THE PIEDMONT REGION [1]

By W. E. McQUILKIN

Assistant forest ecologist, Appalachian Forest Experiment Station, Forest Service, United States Department of Agriculture

INTRODUCTION

Ever since the creation of national forests in the United States and the recognition that artificial reforestation of lands denuded by fire, ax, or plow is an essential part of forest maintenance and administration, the idea of establishing trees or plantations by direct seeding, rather than by planting nursery-grown stock, has intrigued foresters and laymen alike. The primary interest in direct seeding lies in the possibility of reducing reforestation costs. A reduction of no more than $1 per acre would amount to a substantial saving if it could be effected on 50 percent, or even 25 percent, of the 30 million [2] acres in this country estimated to be in immediate need of artificial reforestation. Other advantages over planting nursery-grown stock are that direct seeding, if it could be done successfully, would release reforestation activities from complete dependence on nursery capacities; it would lessen the technical and administrative problems associated with nursery operation; it would make several additional months of the year available for reforestation work (i. e. months in which planting cannot be done); and it would be better adapted to the work habits and equipment of most small farmer landowners. To these may be added the less obvious but from a long-time point of view possibly very significant merits emphasized by Tinsley,[3] viz, that direct seeding possesses the silvicultural advantages of natural reproduction. By this is meant (1) that the trees are allowed to develop normal root systems without the mutilation and possible deformation incident to transplanting, and (2) that opportunity is provided for the laws of natural selection to operate, both of which tend to result in stands of more vigorous and productive trees.

[1] Received for publication November 4, 1944.

[2] United States FOREST SERVICE. REPORT OF THE CHIEF OF THE FOREST SERVICE 1940. U. S. Forest Serv. 42 pp. 1940.

[3] TINSLEY, S. L. DIRECT SEEDING—A REVIVAL. Jour. Forestry 37: 888–890. 1939.

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Key No. F-104

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Direct seeding was tried on a large scale on the western national forests some 30 years ago with so little success that it was soon abandoned as a general practice,[4] and reforestation efforts have since been concentrated almost wholly in planting. There has, however, been a marked revival of interest in the idea of direct seeding in recent years. That interest is evinced not only by the common query of conservation-minded folk as to why man cannot grow trees as nature does, directly from seed, and so do away with much of the overhead cost of operating forest nurseries, but also by several recent or current investigations of direct seeding at various forest experiment stations and schools of forestry. The revival of interest has sprung in large part from the greatly increased emphasis in national policy during the past decade on forestry and conservation generally. It arises also from the realization of the deplorably slow progress in getting the national reforestation job done. At the rate of progress in 1939, about 30 years would be required to complete the job on the national forests, and about 70 years on privately owned forest lands.[5]

Thousands of acres of potentially productive forest land in the Southeastern States lie idle or are only sparsely stocked with growing trees. In the Piedmont region alone of the Carolinas and Virginia, there are nearly a million acres of abandoned farm land in need of artificial measures to insure adequate restocking. In view of the reforestation job to be done in the southeastern part of the United States, and in keeping with the revival of interest in direct seeding, the Appalachian Forest Experiment Station began studies in 1938 to learn whether certain of the native pines could be direct-seeded with reasonably consistent success at less cost than is required for planting. Attainment of this objective involved as a necessary prelude studies of the effects of various treatments and site conditions on germination and early survival, and determination of differences between species in suitability for direct seeding.

Although the work has been restricted to spot seeding and spot treatments on abandoned fields in the Piedmont region, the results are considered to be applicable, in a general way, to other classes of land and to provide some clues, at least, to possibilities of using the same method in the adjoining mountains and Coastal Plain.

The investigation consisted of three major parts or phases, as follows: (1) Extensive exploratory tests of a wide range of treatments on different sites with the three important pine species native to the Piedmont region; (2) corroborative tests on several different areas of the most promising species-site-treatment combinations appearing in the first experiments, together with any modifications or new treatments suggested by the results of those experiments; and (3) field-scale trials to test the utility of the selected methods under practical operating conditions and to determine costs.

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[4] WAHLENBERG, W. G. REFORESTATION BY SEED SOWING IN THE NORTHERN ROCKY MOUNTAINS. Jour. Agr. Res. 30: 637–641, illus. 1925.

[5] United States FOREST SERVICE. A FOREST PROGRAM FOR THE UNITED STATES. SUMMARY OF RECOMMENDATIONS PRESENTED BY THE FOREST SERVICE ON FEBRUARY 16, 1940, TO THE JOINT CONGRESSIONAL COMMITTEE ON FORESTRY. 51 pp. 1940. [Processed.]

EXPLORATORY TESTS

DESIGN OF EXPERIMENTS, MATERIALS, AND METHODS

The exploratory experiments were laid out in 1938 with the following variables:

Place: (1) Lee Experimental Forest in Virginia; (2) Enoree Unit of the Sumter National Forest in South Carolina. (Both places are in the Piedmont region.)

Site: (1) Average (fig. 1)—about 6 inches of A soil horizon present, with plant cover of broomsedge;[6] (2) eroded (fig. 2)—with little or no A soil horizon remaining, and with sparse plant cover. (All sites were on Cecil or Appling soils, which are the predominant series in the region.)

FIGURE 1.—The average site on the Lee Experimental Forest in July. The stakes mark plot corners. Four hardware-cloth screens can be seen in place over seed spots partly hidden in the grass, near the foreground.

Species: (1) Virginia pine (*Pinus virginiana* Mill.); (2) shortleaf pine (*P. echinata* Mill.); (3) loblolly pine (*P. taeda* Linn.).

Season of sowing: (1) Fall—November; (2) spring—early May.

[6] "Broomsedge" refers to grasses of the genus *Andropogon*. The species most commonly found in old fields are *A. virginicus* L., *A. ternarius* Michx., and *A. scoparius* Michx.

FIGURE 2.—The eroded site on the Sumter National Forest in October after the screens had been removed.

Protection against birds and rodents: (1) Seed spots protected by ox-shaped covers of hardware cloth; (2) not protected.

Scarification: (1) Seed spots scalped and the soil loosened with a mattock to a depth of 4 to 6 inches; (2) not scarified.

Raking: (1) Seeds raked into the soil when sown; (2) not raked in.

Mulching: (1) Seed spots covered after sowing with a mulch of pine needles about 1 inch thick; (2) not mulched.

The design of the experiments was factorial, i. e., all possible combinations of species, season of sowing, and spot treatment—96 altogether—were represented at each site at each place. The experimental unit was a plot of 4 seed spots, each about 1 foot in diameter and spaced 4 feet apart. The plots were randomized in blocks, each of which contained 1 plot representing each of the 96 species-season-treatment combinations. Three blocks (replications) were laid out at each site. Hence, for the 2 sites at 2 places, there were 12 blocks, comprising altogether 1,152 plots, or 4,608 seed spots.

The seed used was obtained from Piedmont localities within the State where it was to be sown, except that the loblolly pine seed used in South Carolina came from North Carolina. It was from the crop of the preceding year and was held until needed in sealed cold storage. Seed for the spring sowing was stratified for about 2½ months before sowing in moist sand at 32° to 40° F. The fall-sown seed was not treated. The numbers of seed sown were calculated from the results of germination tests to provide 25 viable seeds per spot. Seeds were counted out separately by spot lots except for Virginia pine in South Carolina. Inasmuch as this seed proved to be less than 20 percent viable, exact counts seemed an unjustified refinement, and spot lots were merely estimated by volume. The fall sowing was done in November 1938, the spring sowing in May 1939. This sequence was followed in order that both seedings should germinate during the same spring.

Intensive records were kept from about June 1 to mid-September of the first year. These consisted of (1) weekly counts of the seedlings on all spots and determination, if possible, of the cause of all cases of mortality; (2) continuous record of air temperature and relative humidity, and daily record of maximum and minimum air temperatures, evaporation from Livingston atmometers, and rainfall; (3) daily record of maximum surface soil temperatures for each of the spot treatments; (4) weekly records of available soil moisture at 0–3, 3–6, and 6–12 inches for the different treatments (available moisture was obtained by subtracting previously determined wilting percentages from the total moisture content obtained by oven drying); (5) examinations of root development for different species and treatments during the latter part of the summer. Extra spots were prepared and seeded within the blocks to provide places for soil sampling and root examinations without disturbing the spots for which survival records were being taken.

Only two examinations were made during the second year—a seedling count in the spring to determine the amount of winter mortality, and one in the fall to check additional losses during the summer. Formal observations on this series of tests were terminated at the end of the second year.

WEATHER CONDITIONS

The two experimental areas in South Carolina and Virginia are much alike climatically, except that the growing season is about 1 month longer in South Carolina. Elevations are approximately 500 feet at both places. The mean rainfall is about 41 inches near the Virginia sites, and about 47 inches at the sites in South Carolina. The rainfall normally is distributed fairly evenly throughout the year, though the fall and spring months are somewhat drier than those of midwinter and midsummer. However, the summer of 1939 was relatively dry in South Carolina and relatively wet in Virginia. In Virginia, the rainfall was above the normal in June, July, and August, and well distributed; consequently, soil moisture never dropped below the wilting point except occasionally in the surface 2 or 3 inches, and the seedlings suffered very little from drought. In South Carolina, on the other hand, the rainfall was 3 inches below normal in June, and 1 inch below in July. Only light showers, ranging from 0.1 to 0.4 inch, fell from sometime in May until July 20. Soil moisture hovered at or below the wilting point to depths of 6 inches or more during the latter half of June and the first 19 days of July. In consequence, there was a good deal of drought injury, especially on the average site, the soil of which was a coarse, sandy loam of low water-holding capacity.

RESULTS

For the sake of brevity, the presentation of results will be restricted to those items that directly pointed the way for further experimentation, or that have a fairly direct bearing on the final conclusions. The records of the site factors and root examinations are mentioned briefly and only as they help to explain some aspect of seedling behavior. For the same reason, discussion of methods of analysis of

the data will be restricted to procedures, usually without statistical tables or detailed explanatory comment. The results will be treated in two parts: (1) Survival at the end of the first summer, and (2) mortality during the first winter and second summer.

Survival at the End of the First Summer

Differences in survival during the first summer were in large part the expression of differences in germination; that is, the treatments and other variables exerted a much greater influence on germination than on subsequent survival. Spot treatments affected survival percentages most markedly when and where growing conditions were most unfavorable; with favorable conditions the treatments made little difference. Drought was by far the most important cause of seedling mortality. Some losses from direct heat injury occurred on the spring-sown plots because of the fact that germination was 2 to 4 weeks later there and the seedlings were still tender, with some still emerging, when high temperatures developed in June. Practically no heat injury was observed among the fall-sown seedlings. The losses from damping-off were not serious, and those caused by insects were negligible.

For the experiment as a whole, recorded germination was about twice as high on the fall-sown as on the spring-sown plots (8,094 and 4,081 seedlings respectively); by the end of the summer higher mortality on the spring-sown plots had increased the ratio of living seedlings to approximately 3 to 1 (5,177 and 1,808 seedlings). No other treatment produced such a generally prevalent high differential in mortality. Spring sowing in May resulted not only in some losses from direct heat injury, but also in higher losses from drought. Many of the root systems of the spring-sown seedlings were not adequately developed to supply them with moisture from the drying soil (fig. 3). Both the higher losses and poorer initial germination occurred for the same reason—because germination was delayed almost to, or until the beginning of hot, dry weather in June.

The poor response of the spring sowing was more marked in South Carolina, where weather conditions were more severe. Sowing in early April doubtless would have given results more nearly comparable to those of the fall sowing, but at best, spring sowing is more likely to fail because it must depend upon artificial treatments of seed to induce prompt germination. An appreciable amount of germination appeared on the spring-sown plots at both places the following year (1940), indicating that the stratification treatment had not been effective for all seeds. Schopmeyer observed similar delayed germination with spring seedings of western species.[7] The theoretical advantage of spring sowing—that it avoids prolonged exposure of the seeds to the foraging of rodents and birds—proved to be of minor importance in these tests. Because the fall sowing was so decisively superior, all subsequent discussion of the results of exploratory tests will pertain to that sowing alone, unless stated otherwise.

[7] Schopmeyer, C. S. second-year results of direct-seeding experiments in the western white pine type using screens for rodent control. Northern Rocky Mountain Forest & Range Expt. Sta. Res. Note 6, 7 pp. 1940. [Processed.]

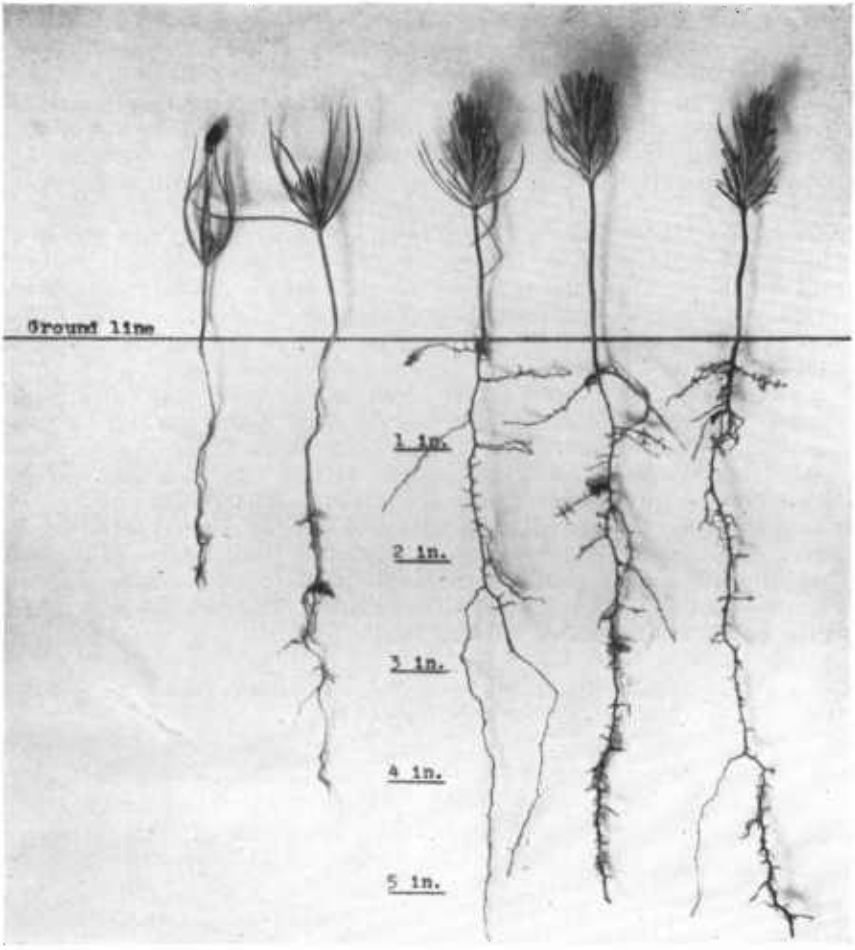

FIGURE 3.—Comparative root development of spring-sown (left of scale) and fall-sown seedlings in mid-June of the first year.

The data from the fall-sown plots were analyzed first according to Yates' methods [8] for factorial experiments; the values used were the numbers of survivors on each plot. Although, from the practical standpoint, percent of stocked spots is a more useful criterion of the success or failure of a method, and normally would show a high degree of correlation with the number of surviving seedlings, considerable discrepancy between the two criteria could readily occur with the small number of spots here involved. Therefore, numbers of survivors were used in the present analysis because, under the circumstances, they theoretically should provide a more sensitive test of treatment effects. Greater emphasis is placed on stocked spots in

[8] YATES, F. THE DESIGN AND ANALYSIS OF FACTORIAL EXPERIMENTS. Imp. Bur. Soil Sci. Tech. Commun. 35, 96 pp. 1937.

discussing the later, more extensive seeding trials. This analysis provides evaluations of the over-all effects of each treatment component or other source of variation; it shows, for example, whether the average survival on all mulched plots was significantly higher or lower than on all unmulched ones, or whether there were significant differences in average survival between species. Furthermore, it provides evaluations of interactions; for example, whether mulching was more or less effective in combination with scarification than is indicated by the sum of the separate effects of mulching and scarification, or whether a given treatment affected one species differently from another. This analysis does not provide for direct comparisons between individual treatment combinations, such as scarified and mulched vs. scarified and raked. For such comparisons, recourse must be had to different procedures to be discussed later.

A single comprehensive analysis including all species at both places was not carried out because the poor quality of the seed of Virginia pine sown in South Carolina was regarded as having disrupted to some degree the otherwise perfect balance of the experimental design. Consequently, the analysis for both places excluded Virginia pine. A second analysis covering all three species was run for the Virginia data alone. Others were run for single species. Actually, some of the less comprehensive analyses were preferable in that interactions did not become so complex and difficult to interpret. The discussion is based on the collective results of all analyses.

TABLE 1.—*Analysis of variance of effect of different factors in the survival of seeded loblolly pine, on 2 sites* [1]

Source of variation	Degrees freedom	Sum of squares	Mean square	*F*
Place	1	10.1	10.1	
Site	1	462.5	462.5	7.41*
Place x site	1	2,436.8	2,436.8	39.05**
Error I (blocks and interactions)	8	499.5	62.4	
Subtotal	11	3,408.9		
Treatments and interactions	60	26,758.8		
Error II (blocks and interactions)	120	9,511.8	79.265	
Total	191	39,679.5		

[1] Lee Experimental Forest, Va.; Enoree Unit, Sumter National Forest, S. C. Total observations: 192.
*Significant at 5-percent level.
**Significant at 1-percent level.

Table 1 and subsequent comment indicate the general analytical procedure. The first section of the table provides tests for place, site, and the interaction between them; the second section provides the value for error II mean square. Where a factorial analysis is carried out, the analysis of variance need not be carried further than here shown. From tables of *t*, 120 degrees of freedom, values of 1.980 and 2.617 are read for the 5-percent and 1-percent levels, respectively. To attain significance at the 5-percent level, therefore, values for main effects and interactions derived from the factorial analysis must equal or exceed $1.980 \times \sqrt{192 \times 79.265}$, or 244.26; at the 1-percent level they must equal or exceed $2.617 \times \sqrt{192 \times 79.265}$, or 322.85.

There were highly significant [9] differences in survival between the two sites at each place, but with the unexpected feature that the relationship between sites was reversed. In Virginia the average site showed higher total survival than the eroded site (1,663 vs. 995 seedlings), as might be expected, whereas in South Carolina the eroded site was much the better (1,732 vs. 787 seedlings on the average site). A major cause of poor survival on the South Carolina average site apparently was the low water-holding capacity of the A soil horizon upon which the seedlings were dependent during their first months. Though not ascertained directly, low water-holding capacity of the A horizon was indicated clearly by its coarse sandy texture and by wilting percentages of about 2 percent, as determined on composite samples with oat plants grown to the point of permanent wilting. Low water-holding capacity in conjunction with low rainfall during the early part of the summer resulted in acute deficiencies of soil moisture and high seedling mortality. The comparatively high survival on the eroded site is none the less surprising in view of the low rainfall. It is not clear why this site gave so much better results than the eroded site in Virginia, where the weather was much more favorable. Whatever the explanation, the South Carolina results demonstrated that some eroded areas, at least, are not unfavorable for germination and early survival of pine, and that some comparatively uneroded ones, if the topsoil is coarser textured than sandy loam, may be decidedly unfavorable if the seedlings are subjected to drought before roots become established in the deeper and moister subsoil.

Despite the converse total effects of site at the two places, comparative behavior of the different species and comparative responses to treatments were fairly consistent in relation to site. These are summarized below. Except as stated otherwise, all effects and differences mentioned were highly significant statistically.

1. Fall sowing, as previously discussed, was decisively superior to spring sowing.

2. Loblolly pine was decisively superior to the other two species. Numbers of surviving seedlings for all sites combined were: loblolly, 2,506; Virginia, 1,556; shortleaf, 1,115. The difference between Virginia pine and shortleaf pine was not significant.

3. Screens were highly beneficial on all sites with all species. Their effect was expressed in both increased germination and lessened mortality. However, germination with certain of the unscreened treatments was ample to prove that rodent and bird depredations were of minor importance. The better results under screens were due primarily to their providing partial shade and some reduction in air movement. Daily maximum surface soil temperatures on the South Carolina eroded site averaged 8° less under screens than outside. Figure 4 shows graphically the effect of screens in lessening mortality on the South Carolina average site, on which seedling losses were highest and consequently most responsive to ameliorative influences.

[9] Throughout this discussion "highly significant" means that by statistical tests the probability is less than 1 in 100 that the difference could be due to chance; "significant" means a probability of less than 1 in 20.

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4. Scarification was beneficial at both places, its effect upon seedling survival being highly significant in Virginia, but significant only at the 5 percent level in South Carolina. Benefits from this treatment were much greater on the average than on the eroded sites. This interaction with site is interpreted as a relation of the plant cover: the average sites were more heavily vegetated; hence, the scarification, by destroying the cover and alleviating the stress of competition on the seed spots, conferred benefits that obviously would not be produced where the cover originally was sparse. Mere loosening of the soil in itself seemed to be of little importance.

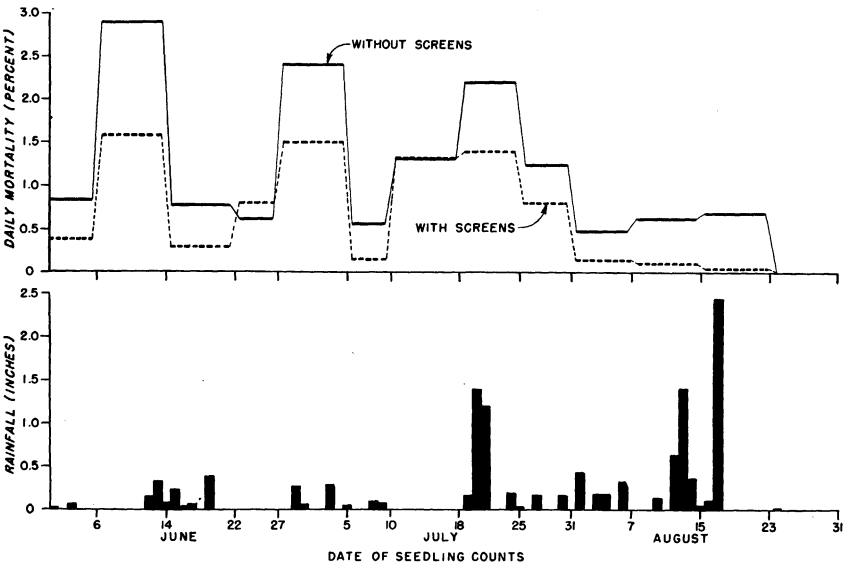

FIGURE 4.—Chart showing effect of screens in lessening seedling mortality (all species combined) on scarified and mulched spots on the South Carolina average site, together with rainfall record, June through August. The dates shown are the days on which seedling counts were made; the horizontal bars represent mean daily percentages of mortality for the intervals between counts. Percentages for each interval between counts of seedlings were based on survival at the last preceding count.

5. Raking did not show a significant main effect anywhere; it did, however, prove to be highly detrimental in combination with mulch (a negative interaction), probably because the seeds were then buried so deep that emergence was poor.

6. Mulching was highly beneficial at both places on the eroded sites; on the average sites differences due to mulch were considerably less because many more seedlings developed on the nonmulched spots. The influence of mulch was expressed mostly in higher germination; subsequent survival was not significantly affected. This germination response was shown most strikingly in South Carolina where, on the eroded site, mulched spots of loblolly pine germinated 1,118 seeds as compared to 145 on the nonmulched spots. Though germination of all species was increased by mulch, the

favorable effects of this treatment were much greater at both places for loblolly than for the other two pines. No explanation of this species interaction is apparent.

As previously pointed out, the routine factorial analysis, from which the above statements are drawn, does not provide for comparisons between the various treatment combinations, though in some respects these are of more practical importance than evaluation of over-all effects of the treatment components. The second phase of the analysis, therefore, consisted of setting up tables of differences in survival between treatment combinations and applying appropriate statistical tests for significance.[10] This was done for each of the four sites with the species combined, and also for all sites and species combined. The most important results derived from these comparisons are as follows:

1. The most successful treatment, all sites considered, was scarified, mulched, and screened (fig. 5). This treatment had a total of 751

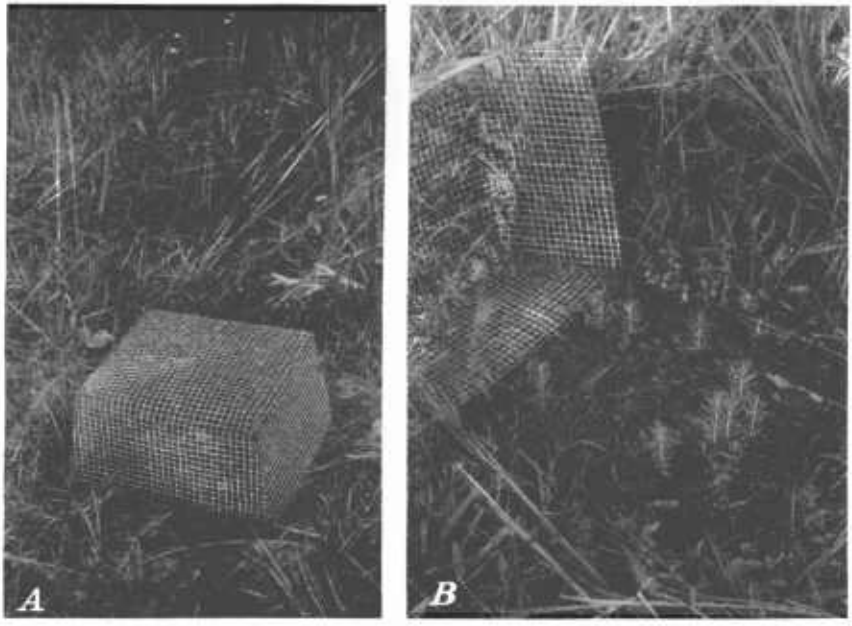

FIGURE 5.—Scarified, mulched, and screened spots on an average site (loblolly pine): *A*, immediately after seeding; *B*, about August 1 of the first year.

survivors in the fall of the first year, in contrast to 67 survivors on the untreated spots. Out of 144 spots, 122, or 85 percent, were successful, i. e., had 1 or more live seedlings. For loblolly pine alone, 94 percent of the spots were successful

[10] The tests were made in the same manner as those for main effects and interactions in the main factorial analysis shown on page 119, using the same error mean square (variance) in a *t* test. To attain significance at the 5-percent level, any difference between two treatments must equal or exceed $1.980 \times \sqrt{24 \times 79.265}$; at the 1-percent level it must equal or exceed $2.617 \times \sqrt{24 \times 79.265}$. Twenty-four is the total number of observations involved in any such comparison.

2. On the average sites, the difference between scarified, mulched, and screened vs. scarified, raked, and screened was not significant (309 vs. 384 survivors); on the eroded sites, the former treatment—with mulch—was superior; the difference was highly significant (442 *vs.* 161 survivors).

3. On the eroded sites, the difference between scarified, mulched, and screened vs. mulched and screened without scarification was not significant (442 vs. 416 survivors); on the average sites the former treatment—with scarification—was superior; the difference was highly significant (309 vs. 36 survivors).

4. When the screened treatments noted in the two preceding paragraphs are compared with their corresponding nonscreened treatments, the former are in every instance significantly better.

5. When the nonscreened treatments are compared with each other, the same general relationships appear as for the screened ones. Scarified and mulched was the best nonscreened treatment, with a total of 418 survivors; on the average sites, scarified and raked was almost as good with 119 survivors as compared with 153 for scarified and mulched; on the eroded sites, mulch alone was somewhat poorer than scarified and mulched (188 vs. 265 survivors), but still the second best nonscreened treatment. The difference in the latter comparison was significant on the Virginia eroded site, but not in South Carolina. For all species on all sites, 101, or 70 percent of the scarified and mulched spots were successful; for loblolly pine alone, 81 percent were successful (fig. 6).

Mortality After the First Summer

Mortality during the first winter was appreciable and showed definite relationships with treatments which warrant comment. Mortality during the second summer was comparatively small, without definite relation to treatments, and need not be analyzed further. Losses during the second winter were negligible. Ordinarily, it appears that most of the seedlings which survive the first year with sufficient vigor to put out a healthy leader the second spring have a good chance to come through unless subjected to drought or other conditions of unusual severity.

Frost heaving was the major cause of mortality during the first winter. Losses were approximately twice as high in the absence of mulch as where mulch was present. For all species and both sowing seasons combined, mortality from frost heaving (expressed in percentage based on fall survival), was 13.6 for the nonmulched vs. 6.5 for the mulched plots in Virginia, and 19.9 vs. 9.2 in South Carolina. On the average sites, frost heaving was more severe on scarified spots than where the sod was unbroken. The effect of mulch in reducing losses from frost heaving was highly significant statistically when the data were analyzed by analysis of variance.

Causes of winter mortality other than frost heaving were inconsequential on the South Carolina sites; in Virginia, however, considerable insect damage occurred, presumably in the late fall and early spring, through root clipping by white grubs, and stem clipping, the agent of which was not observed. The damage was much greater on the average than on the eroded site. On the former the two types of insects accounted for approximately one-half the total mortality from

FIGURE 6.—Unscreened, scarified, and mulched spot on average site (loblolly pine) in October of the first year, indicating that bird and rodent depredations were not serious.

October to June (306 of the 591 seedlings lost). White grub damage was more prevalent in scarified spots, and where there was a good depth of loamy topsoil.

Mortality after the first summer altered the treatment ratings based on first-summer survival only with respect to mulching. Its beneficial effect in lessening losses from frost heaving clearly makes it preferable as a method of seed coverage on all sites, even though on the average sites it did not seem to be essential to germination.

CORROBORATIVE TESTS

DESIGN OF EXPERIMENTS, MATERIALS, AND METHODS

The second phase of the study—corroborative tests of the most promising treatment combinations—was planned and seeding was done in the winter of 1939–40. Thus it was based on only the first

summer's results from the exploratory tests. These may be summarized as follows:

1. Fall sowing was best.
2. Loblolly pine was the strongest species in starting from seed.
3. Both the so-called average sites and eroded sites gave good results with certain treatments.
4. Scarified and mulched was generally the best ground treatment, but scarified and raked was almost equally good on the average sites (in terms of first-summer survival), whereas mulch without scarification was almost equally good on eroded sites.
5. Screens were decidedly beneficial, but (a) it appeared possible to obtain an acceptable percentage of successful spots without such protection, and (b) the benefits of screens appeared to be derived more from their shading effect than from exclusion of rodents and birds.

On the basis of these findings, tests were planned in which loblolly pine was fall-seeded without screens, but with the apparently best ground treatments, on 25 widely scattered sites on the Sumter National Forest, S. C., as follows:

1. Average sites: (a) Newly abandoned, with cover of coarse, dicotyledonous weeds; (b) abandoned 4 or more years, with open cover of broomsedge; (c) abandoned 4 or more years, with dense cover of broomsedge.
2. Eroded sites: (a) Erosion active, with essentially no cover; (b) erosion arrested, with a light cover of poverty grass, bracted plantain, or similar vegetation. Thus there were five site subclasses, each of which was replicated five times in different places.

Scarification was universally done on the average sites and omitted entirely from the eroded ones. Covering the seeds both by raking and mulch was further tested on the average sites; on the eroded ones only mulch was used. Two mulch materials were tried—grass and sawdust. Grass, which was chosen because of its availability, was expected to behave essentially like the pine litter used in the exploratory tests. Since fibrous material tends to become matted and thus obstructs seedling emergence, it was thought that sawdust, being granular, would prove to be an ideal mulch material. Finally, it was desired to test the efficacy of partial shade without excluding rodents and birds. This was done by placing green pine branches over the spots in April at about the time germination was starting. Thus, on the average sites there were six treatment combinations under test: raking, grass mulch, and sawdust mulch, each with and without shade, with scarification as a basic treatment. On the eroded sites there were four combinations: grass mulch and sawdust mulch, each with and without shade, and all without scarification.

The treatment units were plots of 20 spots each. One block, containing 1 plot of each treatment, was laid out at each of the 25 sites. The 5 replications of each site subclass thus provided 100 spots for each site-treatment combination.

All seed used was from one lot which had been collected locally the preceding fall and held in unsealed cold storage until removed for sowing in February. Germination tests were not made; cutting tests, however, indicated 80 to 85 percent of the seed to be sound.

Approximately 15 seeds (by ocular estimate), aimed at providing about 10 germinable seeds, were sown per spot. Subsequent germination on the best blocks indicated satisfactorily close attainment of that objective, and showed also that the natural stratification of the seed on the ground was adequate to induce good spring germination where conditions were otherwise favorable.

Live and dead seedlings on all spots were recorded in June and in September of the first year, and in June of the second year.

RESULTS

The results of the first June examination, in terms of numbers of survivors, were determined by analysis of variance. Differences between the three subclasses of the average sites proved to be not significant, though there were wide variations between individual sites (blocks). The three average site subclasses, therefore, were combined in all subsequent computations. By this grouping, 300 spots were provided for each treatment. The analysis showed that treatment was highly significant. In comparing the methods of seed coverage, grass mulch was found to be superior to a highly significant degree to sawdust mulch or raking into the soil. The results with raking were somewhat poorer than expectations based on exploratory tests. Sawdust mulch also failed to come up to expectations. It was inclined to blow and wash away, or to become mixed with soil as a result of rain action to such an extent that it did not greatly differ from the raking treatment. Shading with pine branches was highly beneficial.

At the first June examination there were 347 live seedlings on the 300 spots grass-mulched alone, and 676 on the 300 spots grass-mulched and shaded. The percents of successful spots were 53 and 78, respectively. The percents were brought down by a few poor blocks, including 1 that was practically a total failure. More than half the blocks were showing good results at that time. Eight of the 15 plots grass-mulched and shaded showed more than 90 percent successful spots. Most of the failures apparently were caused by drought; no evidence of rodent or bird damage was found.

The eroded sites gave considerably poorer results than the average ones, and much poorer than in the preceding exploratory tests. As on the average sites, grass mulch was superior to sawdust mulch and shading was superior to no shading. Both differences were highly significant. Grass mulch with shade, however, showed only 47 percent successful spots; grass mulch alone, 30 percent. It is not clear why the eroded sites did so much worse in these tests than in the exploratory ones. Obscure differences in site properties may be partly responsible; possibly differences in the amount and distribution of spring rainfall also played a part.

Data from the September examination were analyzed in the same way. No changes had developed in the relative ratings of the treatments—grass mulch definitely was the best coverage treatment, and survival definitely was better where partial shade had been provided (fig. 7). Successful spots, however, had dropped on the average sites from 53 to 46 percent for grass mulch alone, and from 78 to 64 percent for grass mulch with shade. On the eroded sites the reductions were from 30 to 26 percent, and from 47 to 39 percent, respectively.

Drought had caused most of the mortality. The rainfall had been from 1.5 to 3.5 inches below normal each month from June through September, except for a torrential downpour in August.

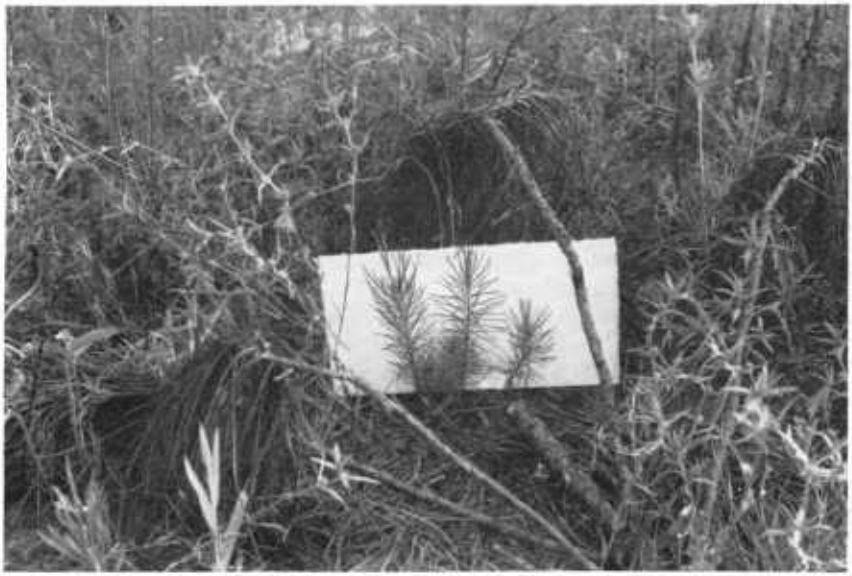

FIGURE 7.—A shaded, grass-mulched spot on an average site in September of the first year. Of the spots so treated, 64 percent were successfully stocked at that time.

The examinations in June of the second year (1941) revealed mortality since the previous September of 11.6 to 32.5 percent for the various treatments, as shown in table 2.

TABLE 2.—*Seedling mortality by treatment and site for the first winter and second spring after germination of loblolly pine*

Treatment	Average sites			Eroded sites		
	September 1940 seedling survival	Mortality by June 1941		September 1940 seedling survival	Mortality by June 1941	
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*
Raked	172	20	11.6			
Raked and shaded	186	26	14.0			
Grass mulch	271	38	14.0	76	11	14.5
Grass mulch and shade	449	131	29.2	154	35	22.7
Sawdust mulch	189	25	13.2	14	2	14.3
Sawdust mulch and shade	281	82	29.2	77	25	32.5

These figures were unexpectedly high, especially in view of the fact that mortality was predominantly drought-caused at a time when the seedlings were well past the stage of maximum vulnerability to that factor. A large part of the mortality occurred during the spring after new growth had started. The year 1941 was unusually dry in

the South Carolina Piedmont. At the nearest Weather Bureau station (Newberry, S. C.), nothing but showers (the heaviest 0.7 inch) had fallen from January 1 to the second week in June. The total deficit for 1941 up to June 10 was about 13 inches, or about 62 percent of the normal precipitation for that period. South Carolina as a whole experienced the driest May since the keeping of records began in 1887. These conditions explain the high drought mortality and the fact that losses continued to occur among thrifty seedlings after the inception of new spring growth. There was only an inconsequential amount of frost heaving during the winter of 1940–41, and some small losses from white grubs. Had frost heaving been as severe as in the preceding winter, total mortality would have been even greater.

A distinctive feature of the mortality data is the much higher losses on shaded than on unshaded spots. Since the shading material was fairly well disintegrated by fall of the first year, it would not seem to be directly responsible. The most likely explanation seems to be that shading saved a good many more or less weak seedlings through the first summer that otherwise would have died soon after germination; these weaklings then succumbed to the rigors of winter or the spring drought and so brought about the marked spread in mortality percentages. Despite their higher mortality, the shaded treatments still had more survivors than the unshaded ones.

Successful spots on the average sites dropped from 46 to 40 percent for grass mulch alone, and from 64 to 62 percent for grass mulch with shade. Nevertheless, 3 plots with grass mulch alone still had 80 percent successful spots; at the other extreme, 3 plots had only 5 percent or none. Though a few scattered spots will, of course, fail later, most spots going into the second year with one or more healthy seedlings ordinarily can be regarded as successfully stocked, and hence, in a general way, can be compared on a percentage basis with survival of nursery-grown seedlings after transplanting to the field. In such a comparison for the locality where these seeding tests were made, i. e., the Sumter National Forest, planting showed a decided superiority. Results from planting on this forest have been good consistently ever since it was started in 1936. Survivals commonly range from 80 to 90 percent, and thus far no plantation has fallen below 250 seedlings per acre which, for administrative purposes, is the minimum number acceptable as satisfactory stocking. Thus, with reference to the present seeding tests, and restricting consideration to average sites, comparison with planting may be stated as follows: (1) Where spots were grass-mulched alone, the average percent successful was about one-half the usual percent survival after planting, and in only 3 of 15 seeded plots were the results as good as in planting; (2) where spots were grass-mulched and shaded, the average percent successful was about five-eighths the usual percent after planting, although results in 7 of 15 plots were as good or almost as good as in planting; (3) for both seed-spot treatments combined, complete or nearly complete failure occurred in 5 of 30 plots, whereas planting properly done almost never fails. There is no reason to expect direct seeding to compare more favorably with planting in localities within the region where planting is less successful. On the contrary,

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situations unfavorable for planting probably would prove in most instances to be even more unfavorable for direct seeding.

The extreme variability, as noted above, in results from plots treated alike would seem to indicate that there were decisive differences between sites, though chance factors, such as erratic distribution of summer showers, doubtless accounted for some of the variations in survival from place to place. As noted previously, the three average site subclasses, based on type and density of herbacious plant cover, did not show statistically significant relationships to seedling survival. As far as was observed, no other gross feature of site or soil within the "average" category, such as soil texture, depth of A horizon, topographic position, etc., showed any consistent relation to seedling behavior. Thus, insofar as site controls seedling survival, the decisive factors are not the more obvious ones, but obscure properties or combinations of properties not easily discernible by inspection in the field.

PRACTICAL FIELD TRIALS

Although the second series of tests fell far short of complete success, the results up to the fall of 1940 seemed sufficiently promising to justify a small field trial. It had been fairly well established in the first experiments that fall or early winter is the best time to seed and that loblolly pine is the species most likely to succeed. The results of the second series of tests confirmed those of the first in showing that screens are not essential for rodent and bird control and that benefits do accrue from partial shading of the spots. The experiments had also shown that a mulch of grass or pine litter is essential, both to promote germination and to protect against frost heaving. Although not experimentally demonstrated, experience indicated that deep scarification was not essential on vegetated sites; the basic requirement appeared to be the removal of potentially competitive vegetation from the seed spots, which can be done by scalping with a mattock or similar tool.

Accordingly, about 11 acres were seeded to loblolly pine on the Sumter National Forest in the fall of 1940. Of these, 9.5 acres had been long abandoned and were mostly covered by fairly dense broomsedge, except for occasional eroded breaks in the slopes. The topography was rolling, presenting various aspects, with southerly and westerly ones predominating. The soil was of the Cecil series, ranging from sandy loam through clay loam to clay, depending on the severity of past erosion. The other 1.5 acres, which had formerly been planted to cotton, had been abandoned 1 year. Here erosion and cultivation had converted the Cecil soil, which probably had been sandy loam, to a friable clay loam. There was only a sparse weed cover. In addition, 2.25 acres in the broomsedge area and 0.6 acre of the newly abandoned field were planted with 1–0 nursery stock by the customary bar-slit method in order to compare both costs and results. All the work was done with Civilian Conservation Corps labor, observing as nearly as possible the same standards of performance as would be followed on regular Forest Service jobs.

On the heavily vegetated fields the seed spots were scalped and mulched with grass raked up nearby; on the newly abandoned,

sparsely vegetated field, no ground preparation was done and pine litter was hauled in for mulch. The spacing was 6 by 6 feet, as in planting. An average of 1.4 pounds of seed per acre was sown, which probably was slightly heavier than the planned rate of 20 seeds (about 15 sound seeds) per spot. As in the tests of the preceding year, all the seed used was from one local collection of the year before which had been held in unsealed cold storage. The seed was 75 to 80 percent sound; germination tests were not made.

Table 3 presents an analysis of the seeding and planting costs for the two cover conditions. Only the major items of labor and materials are considered; no estimate is included for several other lesser items

TABLE 3.—*Analysis of seeding and planting costs per-acre-equivalent of 1,210 spots of loblolly pine*

Field and operation	Man-hours [1]	Pounds of seed or number of seedlings	Costs for labor [2]	Costs for seed or stock [3]	Total cost
Broomsedge:					
Seeding	18.00	1.4	$4.50	$3.91	$8.41
Planting	23.25	1,210	5.81	3.33	9.14
Sparse vegetation:					
Seeding	24.20	1.4	6.05	3.91	9.96
Planting	19.20	1,210	4.80	3.33	8.13

[1] The planting crew was experienced and efficient, whereas the seeding crew was comparatively inexperienced, hence somewhat less efficient.
[2] Civilian Conservation Corps labor computed at 25 cents per hour.
[3] Seed computed at $2.79 per pound; stock at $2.75 per thousand; these are 5-year average costs, respectively, for Forest Service, Region 8, and for the Enoree Nursery on the Sumter National Forest.

of cost, such as supervision and transportation, because they would be essentially the same for both seeding and planting. On the broomsedge area the table shows a cost differential of 73 cents in favor of seeding. Inasmuch as the planting crew was experienced and well trained, whereas the seeding crew was wholly inexperienced and but slightly trained, it should certainly be possible to increase the labor-expense differential by $1 or perhaps even $2 if the two operations were done at the same level of efficiency. The cost comparison on the sparsely vegetated site was less satisfactory, because the seeding was done just after a rain which had made the field too soft for trucks and necessitated carrying the mulch in from the roadside. In this instance the seeding cost almost $2 more per acre than planting. However, in either national forest or private commercial operations where, with proper planning, mulch distribution could be done in dry weather, it should be possible to seed this type of site at a cost as low as or even lower than for planting. Despite these possible cost differentials in favor of seeding, it is obvious that screening, shading, or other additional treatments are not economically feasible except under special circumstances where higher costs might be justified, or on small private jobs where the landowner could contribute his own labor at little or no cost.

The severe drought of the spring and early summer of 1941 has previously been noted in connection with mortality in the second series of tests. Because of that drought, the seeding tests here described failed almost completely. The failure was primarily in ger-

mination; of the few seedlings that did emerge, nearly all had died by June 10 when the drought was broken. On the broomsedge fields only 3.4 percent of the spots showed live seedlings on June 12; the sparsely vegetated field was slightly better, with 11.5 percent successful spots. Neither aspect nor topographic position made much difference in the final results, though germination had been appreciably better on a low-lying area that stayed moist longer in the spring. Sufficient germination appeared on portions of this low area to show that the general failure could not be charged to low viability of the seed, nor to lack of stratification, but was without question caused by the drought. Survival was slightly better on the clayey soils of the eroded spots than elsewhere. In contrast, the planted stock showed 79.3 percent survival on the broomsedge field, and 94.8 percent on the sparsely vegetated one.

Had these tests been wholly or partly successful, they were to have been repeated several times until a substantial amount of data on costs and survival from seeding as compared with planting had been accumulated. However, with these trials ending in complete failure and those of the preceding year showing only 40 percent mean stocking on average sites 1 year after germination, it was clear that direct seeding by the methods here used is a very uncertain operation. It fails by far to meet the requirement of consistent performance. Further tests of the same sort would not have altered that basic fact, regardless of weather encountered or results obtained. For that reason, investigation along the lines herein described has been terminated. If and when further work is done it should be based on methods that offer promise of providing better protection against or escape from drought, and that will cost less, or at least no more, than those used in the experiments here described.

DISCUSSION AND RECOMMENDATIONS

Fundamentally, it is on the basis of costs per acre of successfully established plantation that direct seeding must stand or fall in comparison with planting. It is perhaps fortunate that some of these tests were subjected to droughts, including one of unusual severity, for they emphasize forcefully that direct seeding as done here is much more uncertain than planting—that it is doomed to fail on some sites in all but the most favorable years, and on nearly all sites in the driest years. Therefore, to show an ultimate economic advantage over planting, seeding must be done at considerably lower original costs per acre. How much lower cannot be said as yet, but 25 percent below planting costs perhaps approximates the minimum margin; 50 percent probably more closely approaches the margin required fully to compensate for the more frequent imperfections in stocking that will result from direct seeding, for the occasional thinning that may be necessary when favorable conditions enable several seedlings per spot to survive, and for the extra administrative details involved in grading imperfect stands and reseeding partial failures. Present experience indicates that to undercut planting costs by 25 percent or more while using hand-labor methods would be difficult, if not impossible, without further skimping on cultural treatments already reduced to a minimum.

Both the first and second series of tests indicated that differences between sites may tip the balance to success or failure in years of moderate drought. The logical reaction to this fact is to try to discern the properties of site that predispose it to success or failure; the corollary action then would be to seed only on picked sites. The difficulty is that the determining site properties apparently are obscure and not definitely identified with the more obvious, gross differences in such factors as density of plant cover, soil texture, or topographic position. The only site relationships that have emerged with any degree of certainty from these tests are (1) that very sandy soils are poor seeding sites, and (2) that in the aggregate eroded areas are poorer seeding sites than areas still having a fair depth of topsoil, though in many individual instances this relationship is reversed. For most sites there do not appear to be any easily recognized, reliable criteria by which to judge the likelihood of success or failure. If direct seeding at no more than 25 percent under planting costs is to be of real significance in reforestation work, it must succeed in most years on at least some large, clearly defined class of sites. Falling short of these requirements, it is of doubtful and limited utility, because these requirements and more are met by planting.

The primary conclusion to be derived from the experiments is, therefore, that from a strictly economic standpoint, direct seeding by any of the hand methods herein described cannot be recommended as a substitute for, nor as a large-scale supplement to, planting for the establishment of pines in the southern Piedmont region.

It follows as a corollary that if costs could be substantially reduced by methods other than those tested in these experiments, so that a larger margin of failures could be tolerated, direct seeding might become an important method of reforestation, though it probably would always occupy a position supplemental to planting. By those other methods are meant machine methods of site preparation and also possibly machine seeding. There are two basic approaches to the problem of site preparation by machines: (1) furrowing, either contour, or off-contour with check dams to prevent gullying, and (2) rigorous scarification in rows or strips. The latter might call for the design of special equipment. Both treatments not only offer some promise of reducing costs but also may better conserve and supply moisture, and thus render more sites potentially successful in more years than spot treatment by hand labor.

Though the primary conclusion, as stated above, is definitely negative, the evidence that direct seeding, if tried, would succeed in many instances—possibly more than 50 percent on the average—justifies these positive recommendations:

(1) If a public forestry agency on short notice should be called upon to supply jobs for large numbers of temporary relief laborers, and seed were available, a program of direct seeding would be a well-justified utilization of such labor.

(2) If a public forestry agency could readily obtain more seed at a reasonable cost than could be utilized on existing nursery space, direct seeding on a limited scale probably would be justified as a measure for speeding up reforestation work.

(3) If a farmer wished to reforest a few acres during his winter spare time and had a source of seed, direct seeding would enable him to do it entirely by his own labor. He should understand, however, that he might have to reseed some spots or parts of the area one or more times before obtaining a full stand.

For direct seeding by hand labor, the following is recommended as the minimum treatment for vegetated areas: (1) Scalp spots about 18 inches in diameter with a mattock or hazel hoe, (2) scatter enough seed on each spot to provide 10 to 15 viable seed, (3) cover with not more than 1 inch of grass or pine-litter mulch, well spread to avoid thick lumps or mats. Thickness of the mulch is critically important. It should be not more than about one-half inch thick when settled—just enough to cover the soil. Greater thickness seriously interferes with seedling emergence. On bare areas, or recently abandoned fields supporting only annual weeds, scalping need not be done. Space the spots as in planting, which for the Piedmont region is customarily 6 by 6 feet.

If circumstances permit a greater expenditure of labor or materials for seeding, germination and early survival can be markedly improved by covering the spots with hardware-cloth screens during the first summer, or with brush or green pine branches. When pine branches are used, they must be stuck in the ground or otherwise supported above the spots so as not to mat down on the seedlings.

Seeding may be done with untreated seed from October to February. Stratified seed is required for seeding later in the spring. No seeding should be done after early April.

Within its range, loblolly pine is recommended as more likely to succeed with direct seeding than shortleaf pine or Virginia pine. This, however, does not rule the latter two species out of consideration where for any reason their use is necessary or desirable. It should be noted in considering species that the seeds of both shortleaf pine and Virginia pine run from 2 to 3 times as many per pound as for loblolly pine. Hence, if situations could be found where the smaller-seeded species would respond as well as loblolly pine to seeding, some saving in seed cost probably could be effected by their use. It is quite possible that the small-seeded species could be sown with a fair measure of success within their natural altitudinal range in the mountains where drought is somewhat less prevalent than in the Piedmont. Assuming the same costs per pound and other factors, such as viability and germinative energy, to be equal, the small-seeded species would cost from $1 to $2 less per acre with seed valued at $2.50 to $3 per pound.

SUMMARY

This study of direct seeding of pine was made (1) to evaluate the effects of different treatments on germination and early survival; (2) to compare the suitability for direct seeding of three native southern pines (loblolly, shortleaf, and Virginia pine); and (3) to learn whether it is possible to seed any or all of these pines with reasonably consistent success at less cost than is required to plant nursery-grown stock. All tests were made on abandoned farm land in the Piedmont section of South Carolina and Virginia. The experiment was divided into three

phases: Exploratory tests of a wide range of species-site-treatment combinations; corroborative tests of the combinations showing the greatest promise of success in the first tests; and trials on a field scale, with cost records, of the combinations finally selected as most likely to be of practical utility.

Fall or early winter sowing was found to be better than spring sowing. Loblolly pine started better from seed than either shortleaf or Virginia pine. Scarification or scalping of seed spots was essential on well-vegetated sites, but of little or no benefit on eroded, sparsely vegetated sites. Seeds covered with a mulch of plant litter, such as pine needles or grass, germinated better than those merely raked into the soil. Mulching and raking in combination were unfavorable to germination because the seeds were buried too deep. Mulch inhibited frost heaving. Its benefits were greatest, as regards both germination and frost heaving, on bare, eroded sites.

Birds and rodents did not commit serious depredations to seedlings. Screen covers over the spots were nevertheless markedly beneficial, primarily because of the partial shade cast by them. Similar benefits were obtained by shading the spots with pine branches.

Badly eroded areas in the aggregate were poorer seeding sites than slightly eroded, average ones, but in many instances this relationship was reversed. Very sandy soils tended to be unfavorable. Wide variability in results from apparently similar sites indicated that often there are important differences not readily discernible in the field.

The best treatment tried, all sites considered, was scarification, mulching, and screening. In the exploratory tests, the only ones in which screens were used, the above treatment with loblolly pine resulted in 94 percent successful spots at the end of the first summer. This treatment is impracticable, however, because the application costs more than the planting of nursery stock.

On well-vegetated average sites, the treatment that could be applied with best results at a cost not greater than the cost for planting was scarification and mulching. In the exploratory tests, this treatment with loblolly pine resulted in 81 percent successful spots at the end of the first summer. But in the second series of tests, on 15 widely scattered average sites, it gave only 46 percent successful spots at the end of the first summer.

The seedings on the eroded sites in the second series of tests, which were given only a mulch, had but 26 percent successful spots at the end of the first summer.

The third series of tests, in which the seed spots were scalped and mulched on a well-vegetated site and mulched only on a sparsely vegetated one, indicated that seeding can be done with hand labor at less than the cost for planting, but not at enough less cost to compensate for the inevitable margin of failures attending direct seeding.

In June, immediately after germination in the third series of tests, only 3.4 percent of the spots were successful on the well-vegetated area, and 11.5 percent on the sparsely vegetated one. Nursery-grown seedlings planted during the preceding winter on parts of the same fields showed 79 percent and 95 percent survival, respectively, for the two site conditions.

The major cause of germination failures and mortality after germination was drought. Differences in results for the three series of tests are for the most part expressions of differences in amount and distribution of rainfall from year to year. The low germination of the third series was caused by a spring drought of exceptional severity.

The results of the tests show that although direct seeding may succeed on some sites in some years, none of the methods tested can be recommended from an economic standpoint as a substitute for or as a large-scale supplement to planting for the establishment of pines in the southern Piedmont region.