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Growth and Development of Planted Northern Red Oak on Bulldozed Skidroads after Clearcutting in Appalachian Hardwoods

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Abstract

Artificial regeneration of northern red oak in Appalachian clearcuts on mesic sites is hindered by accessibility and competition from developing vegetation. The use of skidroads as a planting medium was evaluated on two clearcuts with contrasting aspects in north-central West Virginia. Stratified acorns were planted in tree shelters at three positions (cut, middle, fill) on the roadbed and one position (off road) adjacent to the roadbed. Height growth, percent survival, competitive status, and potential crop trees (PCT) were measured after eight growing seasons. Bulk density and percent soil moisture and organic matter also were measured. Height growth was greatest on the off-road and fill positions. The overall height difference (1.5 feet) between off-road and fill positions was less than expected from measurements of soil parameters. Roadbed bulk densities were highest at the cut and lowest at the fill positions. Bulk densities were lowest at the off-road positions. Roadbed moisture content remained about 40 percent lower than that at off-road positions throughout the year. Increased soil depth and organic-matter content from soil deposited at the fill position may have offset some effects of soil compaction. Reduced competition improved the competitive status of all roadbed trees, though competitor trees on average were 4.4 feet taller than PCTs after 8 years. The results indicate that the fill portion of newly constructed skidroads can be used by land managers to facilitate enrichment plantings in Appalachian clearcuts.

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Cover Photo

Planted skidroads in clearcut 6.

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INTRODUCTION

Although many forest stands in the central Appalachians that originated on mesic sites around the turn of the century include a large component of northern red oak (*Quercus rubra* L.), regenerating oak on these sites has proven difficult for many years (Carvell and Tryon 1961; Sander 1988). It is now generally accepted that large, competitive oak regeneration must be present when final regeneration cuts are made (Sander 1972; Loftis 2004). SILVAH guidelines consider advance oak seedlings competitive when they are more than 3 feet tall or have a root-collar diameter greater than 0.75 inch (Marquis et al. 1992). Failure to obtain competitive oak seedlings can be attributed to factors such as acorn predation (Steiner 1995), deer browsing (McWilliams et al. 2003), sporadic seed production (Smith 1993a), interfering understory vegetation (Loftis 1990), slow juvenile growth (Lorimer 1993), reduced fire frequency (Brose and Van Lear 1998), and partial cutting practices (Sander and Clark 1971; Trimble 1973).

Variants of the shelterwood method entail controlling understory vegetation with herbicides or fire, and, when necessary, fencing to exclude deer. These practices seem most promising where advanced seedlings are present (Loftis 1990; Schlesinger et al. 1993; Miller et al. 2004). Still, failures occur when advance seedlings are sparse, too small, or damaged by deer (Schuler and Miller 1995). A major difficulty with this approach is the long time required to obtain competitive oak seedlings before harvest. This wait might be unacceptable to many land managers. It was estimated by Sander and Graney (1993) that 10 to 20 years is required to develop competitive oak seedlings before final harvest is possible. In many cases, landowners prefer an immediate harvest revenue, which precludes developing adequate natural advance reproduction. Planting oaks after commercial harvest operations eliminates the need to wait for advance seedlings, but the feasibility of such practices requires further study.

In certain situations, artificial regeneration using plastic tree shelters (Smith 1993b; Schuler and Miller 1996) to stimulate juvenile growth and protect planted acorns and seedlings is an alternative for shortening the time to develop competitive seedlings. Enrichment planting (Helms 1998) of seedlings with tree shelters on skidroads could provide managers with a regeneration technique for increasing the proportion of selected desirable species or at least maintain their presence on recently harvested areas. Using skidroads as planting sites can facilitate enrichment planting in Appalachian clearcuts, especially in steep topography where it often is difficult to travel off roads to plant and locate planted seedlings, control competing vegetation, and perform the frequent maintenance required with tree shelters.

In the central Appalachians, most timber is harvested with ground-skidding systems that require closely spaced road systems. After evaluating road density on nine logged areas, Kochenderfer (1977) found that bulldozed skidroad density averaged about 1 mile for each 20 acres logged. While this road density limits the number of seedlings that can be established on skidroads, their use allows the spatial distribution of seedlings across most clearcuts.

In this study, we evaluated the growth and development of red oak seedlings established on bulldozed skidroads in two clearcuts in West Virginia. We also quantified major roadbed variables such as soil density, soil moisture, position on roadbed, and soil chemistry that might be expected to influence tree growth on skidroads. This information will aid land managers when using bulldozed skidroads as planting sites in recently established clearcuts in the central Appalachians.

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METHODS
Study Area

Skidroads in two clearcuts located on the Monongahela National Forest in West Virginia were used in this study. The clearcuts have opposing aspects; clearcut 4 (CC4) has an eastern exposure while clearcut 6 (CC6) generally is west-facing (Fig. 1). Because of these different aspects, site index and growth would be expected to differ considerably. Precipitation is distributed fairly evenly between dormant and growing seasons, and averaged 58 inches annually during the study period. The predominant soil on the study area is Calvin channery silt loam (loamy-skeletal, mixed, mesic Typic Dystrochrepts) underlain with fractured sandstone and shale of the Hampshire formation (Losche and Beverage 1967). Slopes average 28 percent on CC4 and 35 percent on CC6. Average elevation of the study area is about 2,600 feet above sea level. The estimated northern red oak site index (base age 50) for CC4 and CC6 is 75 and 70, respectively.

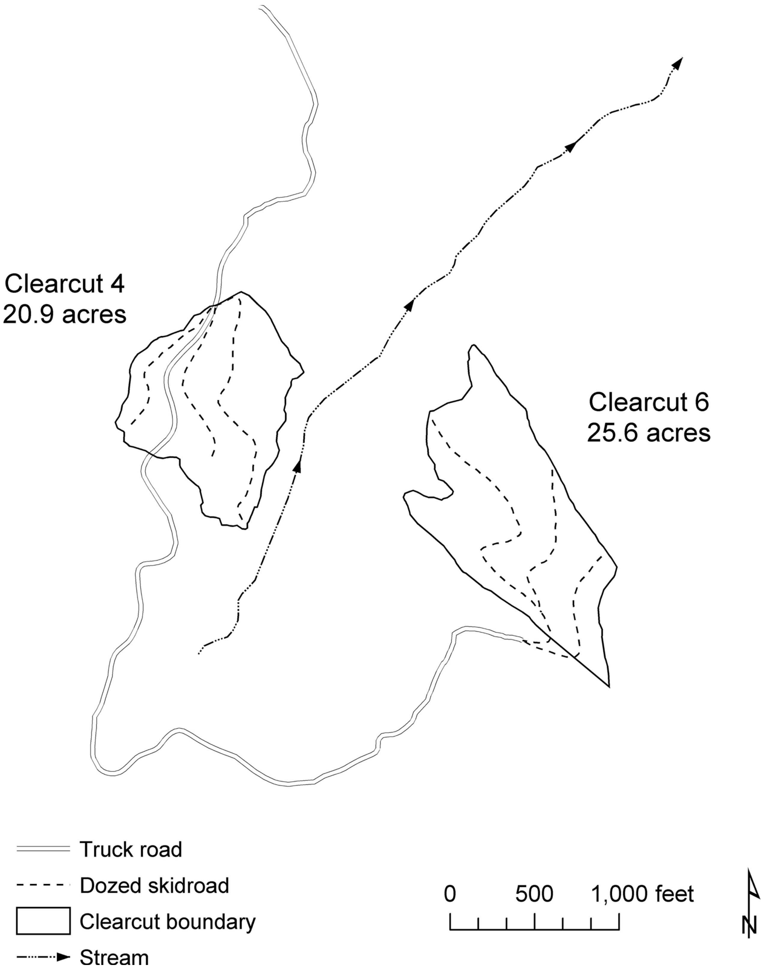

Figure 1.—Map of study area showing locations of the clearcuts.

Design and Treatments

Logging was completed on both clearcuts in the summer of 1995. Three skidroads totaling 3,600 linear feet in CC4 and 3,991 linear feet in CC6 (Fig. 1) were planted using two stratified red oak acorns per spot in the spring of 1996. Acorns were collected locally in the fall of 1995 from well-formed trees growing at about the same elevation as the planting sites. They were stratified by burying them outdoors in rodent-proof wire containers in sand. Acorns were planted in transects on a 10- by 10-foot spacing on each skidroad (Figs. 2-3). The cut position was located between the toe of the cutbank and the inside wheel track, the middle position was between the wheel tracks, and the fill position was outside the outer wheel track on the level fill portion of the roadbed. An off-road planting position was established in the clearcuts for each transect beyond the influence of the roads (Fig. 3) to serve as a control for evaluating performance on the roadbed positions. Planting sites near stumps as well as excessively wet and rocky areas were avoided. Each planting spot was numbered and a 5-foot-tall tree shelter with a 5/8-inch fiberglass T post for support was installed at each spot immediately after planting. Acorns were used rather than seedlings to minimize skidroad disturbances, facilitate planting on the compacted skidroads, and allow natural root development in the different planting mediums. Seventy-six transects were planted in CC4 and 87 transects were planted in CC6.

Herbicide Treatments

Competing vegetation around each tree shelter on alternating transects (hereafter referred to as sprayed vs. unsprayed) was controlled by broadcast spraying a

[1]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or Forest Service of any product or service to the exclusions of others that may be suitable.

Figure 2.—Planted skidroad (June 1996) showing planting positions used in the study.

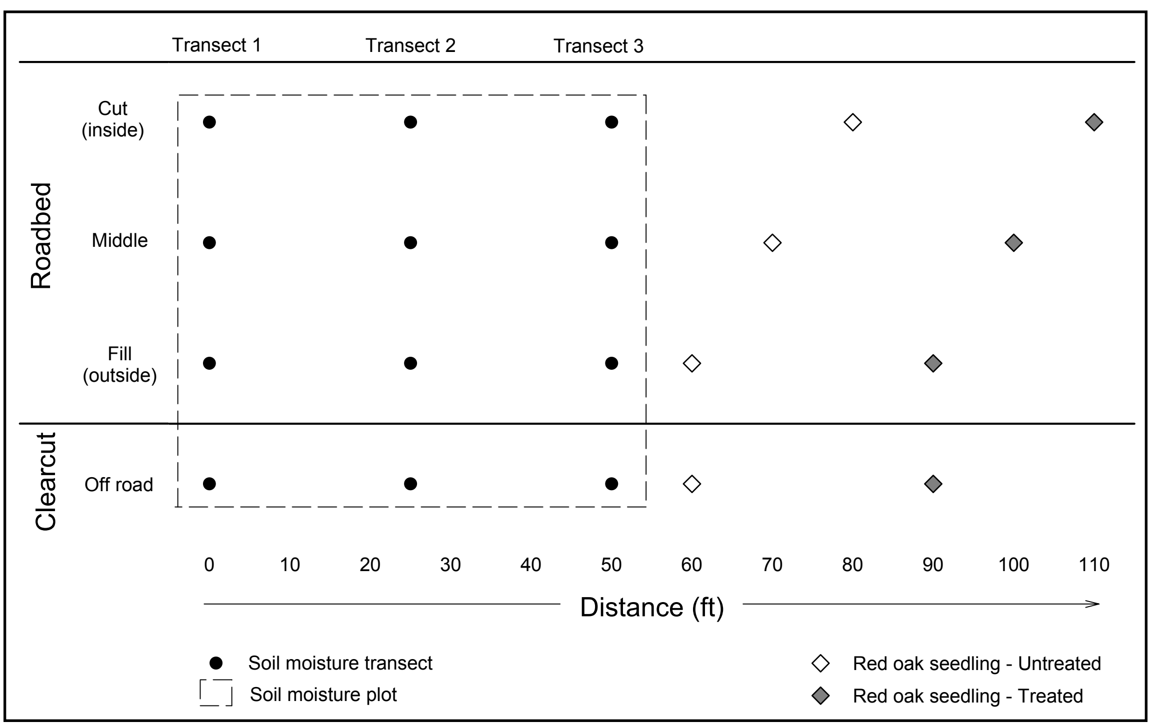

Figure 3.—Diagram of a soil moisture-density plot and planting pattern used on skidroads.

2-percent solution of glyphosate (N-(phosphonomethyl) glycine) as Roundup Pro[1] (41 percent) in water with a backpack sprayer. Herbicide was first applied in September 1996 primarily to control grass that had been planted on the skidroads for erosion control and to control native vegetation such as *Rubus* spp., grasses, and woody vegetation developing around the off-road tree shelters. Additional herbicide treatments for trees established on the skidroads were deemed unnecessary. Two additional broadcast herbicide treatments were applied around the off-road trees in September 1997 and 1999 to ensure survival and development of the off-road trees, where competing vegetation was more intense. A 4-foot-radius circle was sprayed around the off-road trees with the same herbicide and solution concentration used in earlier treatments.

Tree Measurements

Total height to the nearest 0.1 foot, survival status, and animal damage were recorded for each tree. Trees were measured during April in 1997, 1998, 1999, 2000, 2001, and 2004, but only 2004 measurements are analyzed here. In addition to the regular measurements in 2004, potential crop trees (PCT) that had developed from the planted acorns were selected. These trees were in an intermediate or higher crown class, at least 6 feet tall, and of good form and vigor. Smith and Lamson (1986) recommended restricting crop-tree selection in intermediate crown classes to relatively tolerant trees such as oaks and maples. Trees more than two-thirds of the height of crop trees where crowns extended within 10 feet of a crop tree crown were designated as competitor trees. Total height to the nearest 0.1 foot and species were recorded for the tallest competitor trees around each crop tree. The competitive status (number of free-to-grow crown sides) was determined for each PCT using the crown-touching, crop-tree release concept (Lamson et al. 1988). This was determined by dividing each PCT crown into four quadrants beginning at due north and proceeding clockwise around tree crowns. Crown sides were considered free to grow so long as competitor tree crowns did not touch or overlap PCT crowns.

Soil Moisture and Density

Three plots were established randomly on each of the roads in the clearcuts to measure soil moisture and density. Each road was divided into numbered 50-foot segments; four segments were chosen randomly for the location of the soil density-moisture plots and trenches for collecting soil samples. The highest numbered segment selected on each road was used for the soil trench. Each plot (Fig. 3) consisted of three transects of four measurement points located at the road positions described previously for the planting spots. Soil-moisture measurement points were offset (outside the 4-foot spray circle) where necessary to avoid the influence of the spray treatments.

A Troxler Model 3440 Nuclear Surface Moisture Density Gauge[1] was used to measure dry soil bulk density (g cm^{-3}) and moisture content (% by volume) at the 4-, 8-, and 12-inch depths. The following procedure was used at each measurement point: (1) a metal rod 0.75 inch in diameter was pounded into the roadbed and then extracted, (2) the soil surface was leveled to avoid air spaces at the soil-instrument interface, (3) a 1-minute reading was made at each depth as defined earlier, and dry density and moisture content were recorded, and (4) after the measurements were made, a 6-inch piece of 0.75-inch plastic pipe with a 4-inch square plywood cap was inserted into each hole.

A complete set of moisture measurements on both clearcuts required 2 days to complete. We used weather forecasts to avoid periods of unsettled weather so that measurements were not interrupted by rain storms. The first set of measurements was made in August 1995 and continued until April 1999. Depending on weather conditions, monthly measurements usually began in April and ended in December. After evaluating the data in July 1997, we determined that sampling intensity could be reduced to one plot per road. Beginning in July 1997, we continued measurements on one representative plot on each road in both clearcuts. This change enabled us to complete measurements on both clearcuts in one day.

Soil Analysis

In January 1999, trenches 18 to 24 inches deep were dug across three skidroads with a backhoe at randomly chosen locations in each clearcut. Soil samples for organic matter determinations were collected at 2-foot intervals along these trenches at depths of 6, 12, 18, and 24 inches. In several cases, unweathered bedrock prevented sample collection at the 24-inch depth. Control soil organic-matter samples were collected near each trench at the same depths from pits located on undisturbed soil adjacent to the road. Percent organic matter was determined at the USDA Forest Service's Timber and Watershed Laboratory at Parsons, West Virginia, by loss on ignition at 400°C for 4 hours.

Statistical Analysis

Initially, all data sets were tested for normal distributions using the Shapiro-Wilks test (SAS Inst. 2003). No data set was distributed normally. Several common transformations were applied to data on height, bulk density, soil moisture, and organic matter, though only a log transformation of organic matter improved normality. Data for the two clearcuts were analyzed separately because the effect of aspect was considered large enough to be of biological significance. Transects were considered the experimental unit, with seedlings within transects the sampling unit. Because of the spatial requirement of roadbed sampling sites, treatments could not be randomly selected within a transect. However, because the spacing was far enough apart that seedling growth would most likely not be affected by adjacent seedlings between or among transects, we considered the samples to be independent. Tree height was determined each year, but analyzed statistically only for 2004. Tree height, bulk density, and soil moisture were tested by analysis of variance (ANOVA) on ranks and the Tukey-Kramer HSD test for mean differences. Soil organic matter was tested by ANOVA and the Tukey-Kramer HSD test for mean differences (SAS Inst. 2003).

RESULTS

Percent survival based on the initial number of planted positions and number of PCTs after eight growing seasons are shown by planting position for the two clearcuts in Table 1. The two clearcuts were analyzed separately because of a priori decisions about differences related to aspect. Survival averaged 77 percent in CC4 and 81.1 percent in CC6. There were no consistent differences in survival between sprayed and unsprayed transects. The percentage of PCTs (percentage of original

Table 1.—Number of trees, percent survival, and potential crop-tree percentages, by clearcut, planting position, and treatment after eight growing seasons

	All trees				Potential crop trees			
	Unsprayed		Sprayed		Unsprayed		Sprayed	
Planting position	Number of trees	Percent survival	Number of trees	Percent survival	Number of trees	Classified as PCT	Number of trees	Classified as PCT
						Percent		Percent
			Clearcut 4					
Off road	30	76.9	29	78.4	23	59.0	26	70.3
Cut	26	66.7	31	83.8	8	20.5	15	40.5
Middle	29	74.4	32	86.5	14	35.9	17	45.9
Fill	30	76.9	27	73.0	22	56.4	21	56.8
			Clearcut 6					
Off road	36	81.8	37	86.0	32	72.7	34	79.1
Cut	33	75.0	31	72.1	19	43.2	18	41.9
Middle	33	75.0	35	81.4	16	36.4	24	55.8
Fill	41	93.2	36	83.7	32	72.7	32	74.4

planting sites that qualified as PCTs in 2004) was higher for sprayed trees in both clearcuts (Table 1). PCTs averaged 43 percent and 53.4 percent for unsprayed and sprayed trees in CC4, and 56.3 and 62.8 percent, for sprayed and unsprayed trees in CC6. The number of PCTs was highest at the off-road and fill positions in both clearcuts. These relationships were consistent across herbicide treatments. The number of PCTs was lowest at the cut and middle road positions.

Mean height (feet) of all trees by planting position is shown for each clearcut in Figure 4. Analysis of 2004 height data revealed that trees growing in the off-road positions generally were the tallest, followed closely by those in the fill position. Trees growing in the middle and cut positions were significantly shorter than trees in the fill or off-road positions. The average height of off-road trees was about 1.5 feet greater than that of trees growing on roadbed fills. Trees on the cut and middle road positions averaged 5.9 and 6.8 feet in CC4 and CC6, respectively.

In CC4, the average height of unsprayed and sprayed off-road trees in 2004 was 9.3 and 11.1 feet respectively (Fig. 5). The average height of unsprayed and sprayed off-road trees in CC6 in 2004 was nearly identical at 10.5 feet. In 2004, the average height of fill position trees was 8.1 and 9.5 feet in CC4 and CC6, respectively. Sprayed trees on road fills were on average about 1 foot taller than unsprayed trees in both clearcuts.

The average height of PCTs and competitor trees are compared in Table 2. Except for the sprayed cut position, competitor trees in all planted positions in CC4 were significantly taller than the PCTs. In CC4, the competitor trees around unsprayed and sprayed PCTs were an average of 5.1 and 4.2 feet, respectively. In CC6, the average height of both sprayed and unsprayed trees was nearly 5 feet greater than that of potential crop

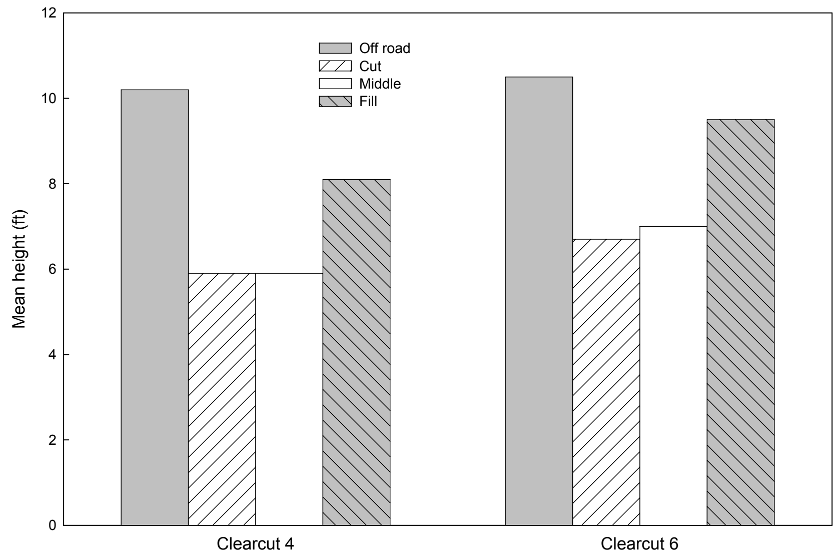

Figure 4.—Mean height of all trees by planting position after 8 years.

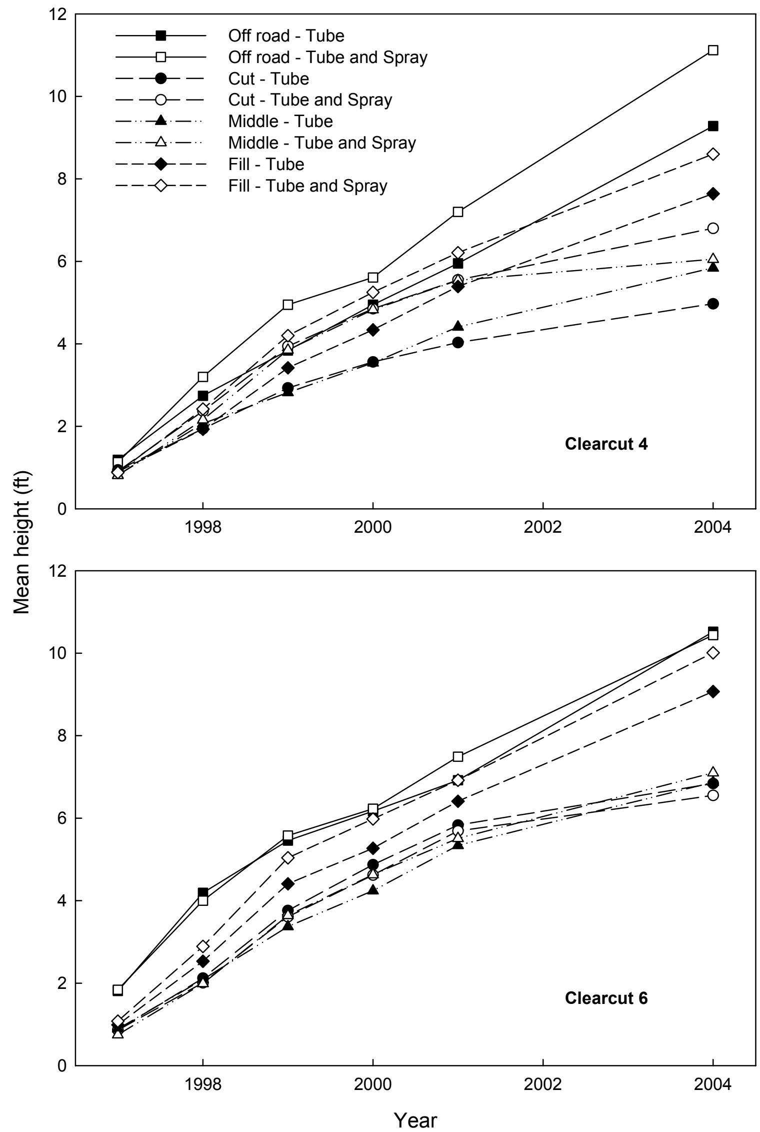

Figure 5.—Mean height (1997-2004) of all trees by planting position and treatment for each clearcut.

trees after eight growing seasons. The average distance between competitor tree and PCT crowns was 1.6 feet.

Average competitive status (number of free-to-grow sides of the PCT) was lowest for unsprayed off-road trees in both clearcuts (Table 2), where less than one side of PCT crowns were free to grow. But competitive status increased to an average of three free-to-grow sides in those planted at the off-road sites and receiving herbicide treatment. The middle road planting positions in both clearcuts generally had the highest competitive rating regardless of treatment. The average competitive status of unsprayed and sprayed roadbed positions was 3.1 and 3.4 feet respectively, when data from both clearcuts were combined. This suggests that herbicide use did not significantly enhance the competitive status of PCTs except in the off-road position. The most common competitor trees in both clearcuts were yellow-poplar (*Liriodendron tulipfera* L.), black birch (*Betula lenta* L.), and black locust (*Robinia pseudoacacia* L.). Yellow-poplar was the most common competitor in CC4 and black birch the most common competitor in CC6. There was a significant height difference (α= 0.05) between unsprayed and sprayed PCTs competitor trees except at the sprayed cut position in CC4.

Figure 6 shows mean bulk density (g cm^{-3}) by planting position, year, and soil depth for both clearcuts. Roadbed bulk densities at all three depths were highest at the cut position and lowest at the fill position in both clearcuts. Bulk densities were consistently lowest at the off-road positions. Across all depths on the roadbeds in both clearcuts, mean bulk density was 27 percent higher than at off-road positions on adjacent undisturbed soils. Mean soil density varied significantly (α=0.05) with planting position

Table 2.—Average height and competitive status of potential crop trees (PCT)[a] and average height of tallest competitor tree, by clearcut, planting position, and treatment after eight growing seasons

Planting position	Unsprayed: Number of trees	Unsprayed: PCT height	Unsprayed: Competitor height	Unsprayed: Competitive status[b]	Sprayed: Number of trees	Sprayed: PCT height	Sprayed: Competitor height	Sprayed: Competitive status[b]
		-------- Feet --------				--------Feet --------		
Clearcut 4								
Off road	23	10.6a[c]	16.0b	0.8	26	11.5a	17.1b	3.0
Cut	8	7.6a	12.3b	3.0	15	8.7a	10.5a	3.5
Middle	14	8.2a	14.3b	3.1	17	7.6a	13.1b	3.9
Fill	22	9.5a	13.5b	3.1	21	10.2a	14.1b	3.5
Clearcut 6								
Off road	32	10.8a	15.9b	0.3	34	11.0a	18.2b	3.0
Cut	19	8.4a	14.1b	2.8	18	8.4a	13.2b	3.1
Middle	16	9.3a	14.0b	3.4	24	8.8a	12.3b	3.4
Fill	32	10.6a	15.7b	2.9	32	10.7a	14.2b	3.1

[a] Trees selected for PCTs were in an intermediate or higher crown class, at least 6 feet tall, and of good form and vigor.
[b] The average number of PCT sides (0-4) free to grow where competitor and crop-tree crowns were not touching or overlapping.
[c] For a given planting position, PCT and competitor mean heights followed by different letters are significantly different at α=0.05 (ANOVA on ranks followed by Tukey-Kramer HSD test).

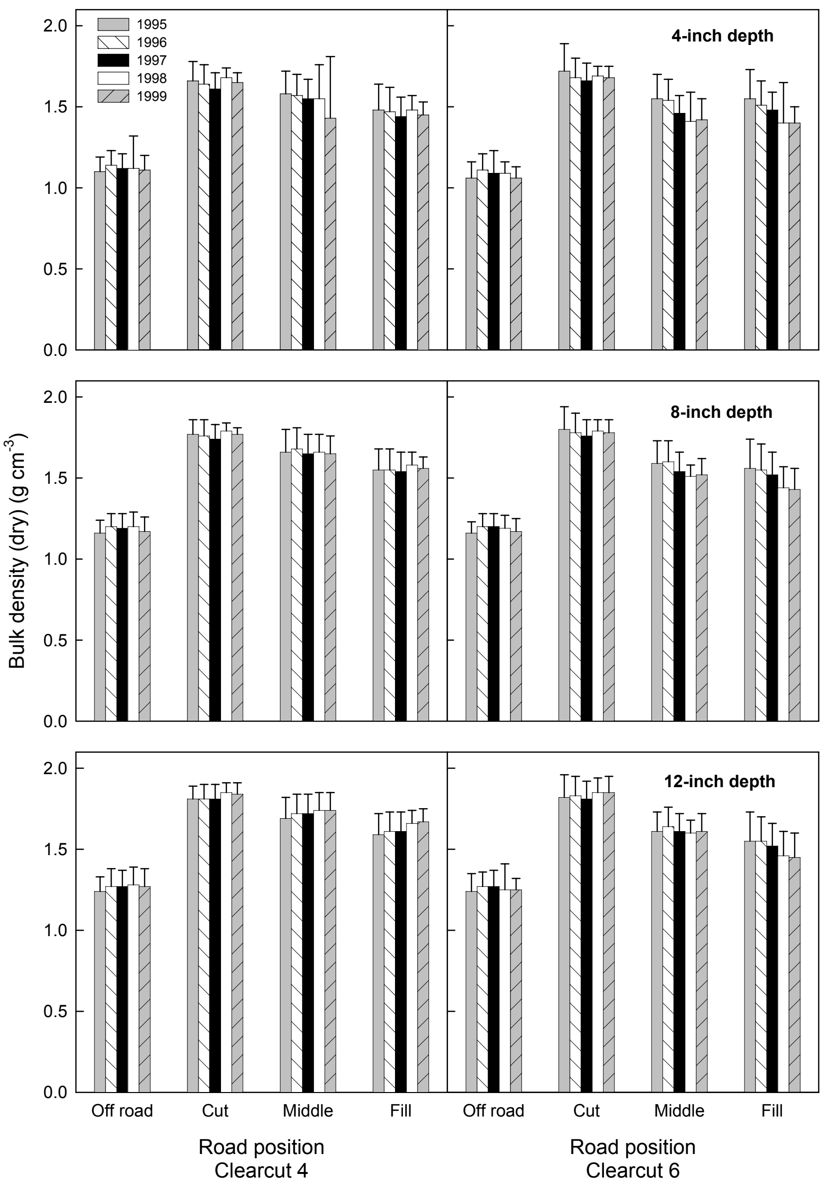

Figure 6.—Mean soil dry bulk density for both clearcuts by planting position (1995-99) at depths of 4, 8, and 12 inches. Bars represent one standard deviation.

the off-road position and lowest at the cut position in both clearcuts (Fig. 7). Average soil moisture content at the 8-inch depth was 29 and 13.8 percent at the off-road and cut positions, respectively. Moisture content on the roadbeds increased from the cut toward the fill. There were small but significant declines in soil-moisture content with depth at all positions.

Mean monthly soil-moisture trends for the off-road and roadbed positions and precipitation for the 5-year period (1995 to 1999) are shown in Figure 8. Soil-moisture depletion and recharge patterns were similar but soil-moisture content on the off-road positions in the clearcuts remained about 40 percent higher than on the roadbed positions throughout the year. Moisture contents on both off-road and roadbed positions were highest during the dormant season and lowest during mid-summer. Soil-moisture content declines by March, reaching its lowest level in July. Except for a brief decline in September-October, it gradually returns to dormant-season levels.

Mean organic matter by planting position and depth is shown in Figure 9. ANOVA indicated significant differences between some planting positions and soil depths. Within the roadbed, organic-matter content was highest on the fill and lowest on the cut position. Differences in organic-matter content were significant (α=0.05) between the fill and cut positions and between those and other planting positions. Differences in organic-matter content between off-road and middle of the road planting positions were small and nonsignificant. Calculated over all four sampling depths, mean organic-matter content was 1.80, 3.93, 5.01, and 3.65 percent for the cut, middle, fill, and off-road planting positions, respectively. In general, organic-matter content declined with soil depth (Fig. 9). Generally, fill positions showed the effects of additions of

and soil depth. Mean bulk densities at the 8-inch depth were 1.19 and 1.77 g cm^{-3} at the off-road and cut positions, respectively. Differences among positions on the roadbeds, though significant, were much smaller. There was a small but significant increase in bulk density with depth at each planting position.

Bulk density and soil moisture were inversely related, and differences in soil moisture content were significant (α=0.05) between all planting positions in both clearcuts. Mean soil moisture content (% by volume) was highest at

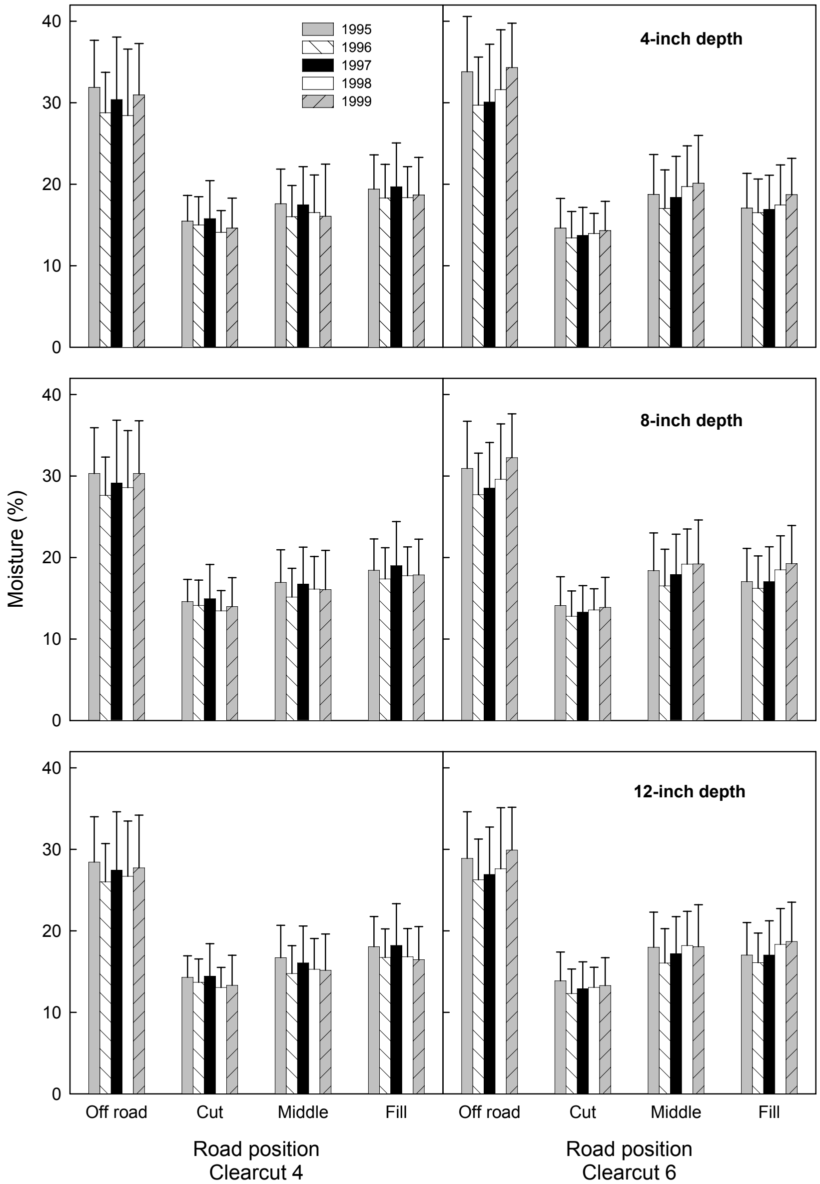

Figure 7.—Mean soil-moisture content for both clearcuts by planting position (1995-99) at depths of 4, 8, and 12 inches. Bars represent one standard deviation.

organic matter rich soil, while soils in the cut positions showed removal.

DISCUSSION

Overall survival after eight growing seasons was acceptable (Table 1) and did not consistently improve following the use of herbicides. Tree survival was affected more by damage from black bear (*Ursus americanus*) than from soil parameters or competition (Fig. 10). Bear apparently use the roads for travel because damage was more prevalent on trees growing on roadbeds than on off-road trees in clearcuts. In 2004, 43 percent of the trees measured had sustained some type of bear damage, and failure to classify trees as PCTs often was the result of bear damage. The relatively high percentage of PCTs at the off-road and fill planting positions is attributed to the better growing conditions and less bear damage at those positions.

The percentage of trees classified as PCTs on CC4 generally was greater in sprayed than unsprayed transects, while the herbicide application had less effect on the percentage of PCTs on CC6. The additional growing space provided by the spray treatments generally increased the percentage of trees classified as PCTs. This favorable response to the spray treatments was more pronounced on CC4, where competition was more intense.

The high percentage of trees qualifying as PCTs on CC6 is attributed to the ability of red oak to be more competitive on lower quality sites. Smith (1983) found that red oak seedlings growing on a fair site (site index 62) in West Virginia were more competitive with intolerant species than on good sites (site index 75). When northern red oak and yellow-poplar were grown from seed in containers with varying resources, red oak seedlings outgrew yellow-poplar under lower levels of light intensity, soil moisture, and soil fertility. However, Kolb et al. (1990) found that this relationship was reversed when resource levels were high. The authors concluded that red oak was better adapted to compete in moderately unproductive environments. The difference in the percentage of trees classified as PCT between the sprayed and unsprayed generally was smaller in CC6 than in CC4, an additional indication of lower site quality in CC6.

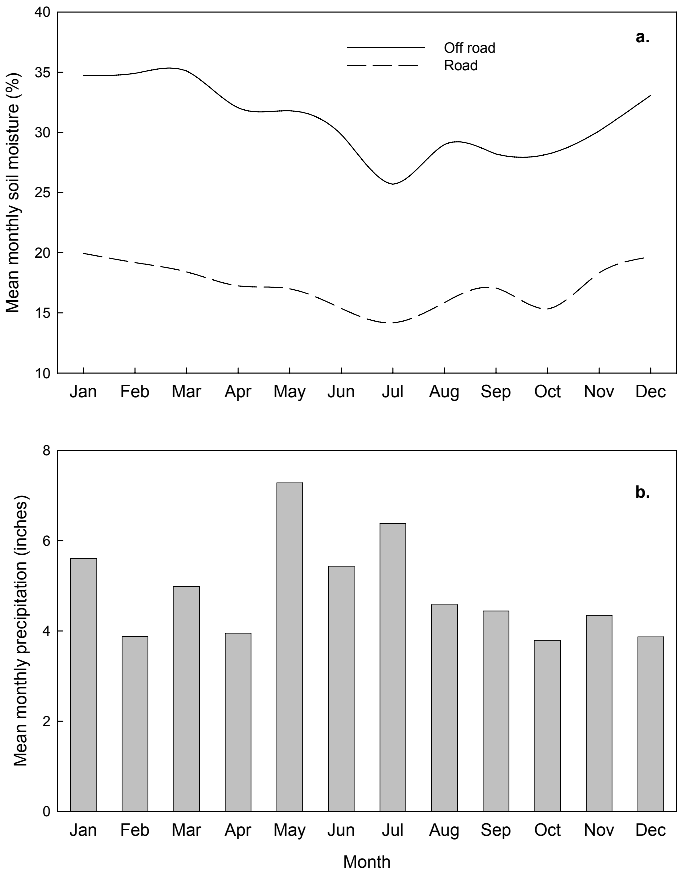

Figure 8.—(a) Mean monthly soil-moisture trends for off-road and roadbed planting positions, and (b) mean monthly precipitation (1995-99).

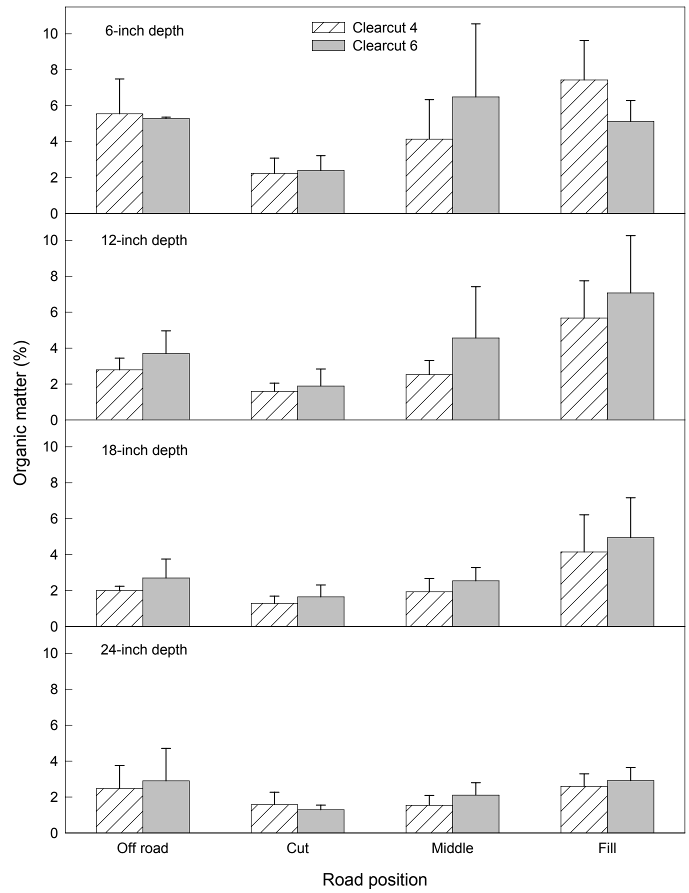

Figure 9.—Mean soil organic matter at depths of 6, 12, 18, and 24 inches by planting position for both clearcuts. Bars represent one standard deviation.

Height growth of trees growing on the fill portion of the roadbeds was comparable to that observed on the off-road positions. The overall height differential of 1.5 feet between off-road and fill positions is less than might be expected from the large differences in some soil parameters. The increased soil depth and organic matter content that resulted from the additional soil deposited on the fill portion of the roadbed (Fig. 11) would be expected to improve growing conditions and may have lessened the effect of compaction from road construction. Trimble and Weitzman (1956) found that total soil depth is an important variable that can be used with aspect, slope position, and slope steepness to estimate the productivity (site index) of most forest land in the northern Appalachians. Height differences between the off-road and fill positions are expected to decline as these trees grow older and their roots begin to fully occupy the additional growing space available on the road fills. The reduced growth observed on the middle and cut positions is attributed to adverse impacts created during road construction, including removal of top soil, reduced soil depth, exposure of denser subsoils, and, of course, soil compaction.

Differences in height-growth response between the two clearcuts to the herbicide treatments can be attributed to competition differences that reflect site quality and species composition. Vegetation development following harvesting was more vigorous on the more productive site found on east-facing CC4. In addition, pin cherry (*Prunus pensylvanica* L.), which has a lower crown density than other trees, accounted for 13 percent of the competitor trees on CC6 but only 2 percent on CC4.

The lack of a large difference in PCT height within planting positions between unsprayed and sprayed trees (Table 2) is perhaps not surprising. While height growth usually is consistent over a wide range of stand densities

Figure 10.—Bear damage to a tree shelter and red oak tree.

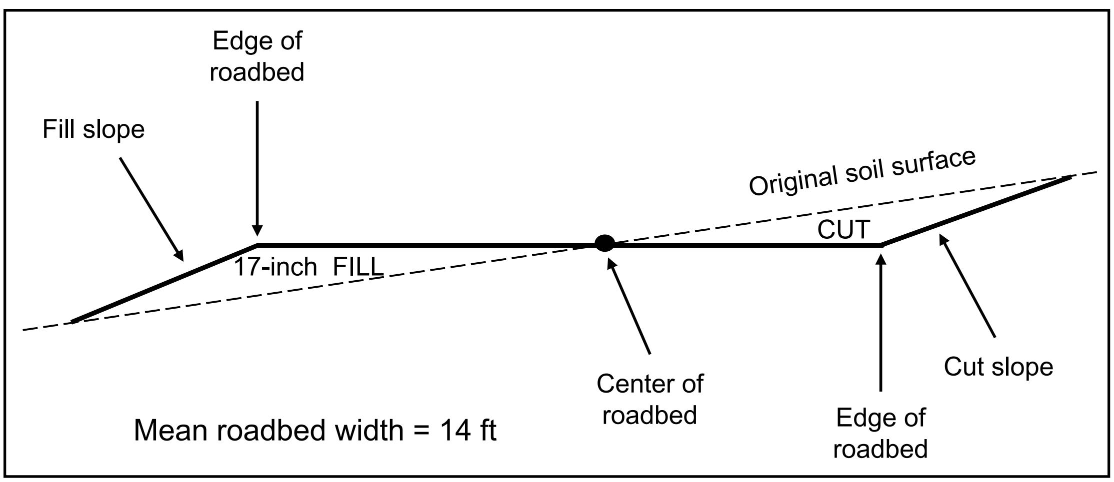

Figure 11.—Typical cross section of a skidroad showing how soil depth is increased on the outer portion of roadbeds.

(Smith 1986), responses to release have been variable. Some investigators, e.g., Smith and Lamson (1983) and Wendell and Lamson (1987), found that height growth was not affected by crop tree release treatments. Other researchers (Trimble 1974; Ward 1995) reported initial declines in height growth after the release of dominant and codominant oaks. However, height growth was not affected 2 to 4 years after release. In comparing the 2-year response of 8-year-old red oak to a 5-foot radius and a light overtopping only release, Schuler and Miller (1999) concluded that height growth is related to the degree of release and recommended light annual releases.

The faster initial growth rates of competing species on mesic sites is a major impediment to growing red oak on these sites (Miller et al. 2004). In this study, the height differences between the planted red oak and competitor trees, ranging from 4 to 5 feet (Table 2), were similar to those reported by Schuler and Miller (1999) for red oak of similar age planted on a mesic site in West Virginia. In this study, reduced competition on these roadbeds has had a positive influence on the competitive status of the PCTs. Nearly all the PCTs on the roadbeds, regardless of treatment, have at least two or three sides of their crowns free to grow after eight growing seasons. Overall, 82 percent of the roadbed trees and 44 percent of the off-road trees had competitive status ratings of 3 or higher. The beneficial effects of the spray treatments are most apparent on the off-road trees, where competition was more intense. The unsprayed off-road trees had mean competitive status ratings of less than 1 compared to 3 or higher for sprayed trees. The overtopped trees would not be expected to respond to release, but those PCTs that still have two or three sides free to grow would be expected to benefit from a crown-touching release at this time.

Compacted soils often have characteristics that are unfavorable for plant growth. These include high bulk densities and reduced porosity, which can restrict movement of air and water (Adams and Froehlich 1981). The higher bulk densities measured on the roadbeds in this study (Fig. 6) were attributed to compaction by logging traffic and exposure of denser subsoils, especially on the cut portion of the roadbed. The overall mean roadbed bulk density of 1.63 g cm^{-3} across all planted positions and depths could be expected to impact tree growth. Mean bulk densities were lower at the fill position (1.53 g cm^{-3}) but still high enough to affect growth. Tworoski et al. (1983) found that root growth of white oak seedlings in a growth chamber was significantly reduced in a silt loam soil when bulk density was increased from 1.0 to 1.5 g cm^{-3}. Simmons and Pope (1985) reported significant declines in rooting depth for sweetgum (*Liquidambar styraciflua* L.) and yellow-poplar seedlings as bulk density of a silt loam increased from 1.25 to 1.55 g cm^{-3}. On the basis of analyses by Adams and Froehlich (1981), increases in roadbed density observed in this study translate into projected declines in seedling height growth of 24 percent. Our data partially support these analyses. Using the off-road position as a control, height declines average 22 percent on CC4 and 14 percent on CC6. Because of the reduced growth impacts on the fill portions of the roadbeds, we hypothesize that some aspect of site quality (moisture, temperature, or nutrient availability) can compensate for some adverse effects of high bulk density.

Although no declines in bulk density over the 5-year measurement period were observed, other researchers have documented gradual reductions in bulk density on compacted soils over time due to root activity and freeze-thaw and wet-dry cycles. Dickerson (1976) estimated that wheel-rutted soils in Mississippi require about 12 years to recover, though recovery periods longer than 23 years were reported in central Idaho (Froehlich et al. 1985). Recovery times longer than 4 years were predicted for silt loam soils compacted on primary skidroads in Indiana (Reisinger et al. 1992). Helvey and Kochenderfer (1990) reported a slight increase in soil density and a small decline in soil moisture after measuring soil density and moisture for 30 months on two newly constructed forest roads in the central Appalachians. They attributed these changes to compaction from raindrops and reduced infiltration. After bulk density diminishes, tree growth on the roadbed might be expected to approach that observed in the off-road position.

The inverse relationships between bulk density and soil moisture (Fig. 7) probably can be attributed to reductions in both moisture storage capacity and infiltration caused by soil compaction. The largest soil-moisture deficits were recorded in midsummer on both the roadbed and off-road positions when evapotranspiration losses were high (Fig. 8). We were surprised by the magnitude of the difference (40 percent) in moisture content between roadbed and off-road positions in an area that receives large amounts of precipitation that is well distributed throughout the year. Since these differences persisted during the dormant season, reduced moisture storage and infiltration capacity probably were the dominant factors influencing moisture content. Troendle (1970) compared soil-moisture losses from forested and uncompacted areas maintained barren with herbicides near this study area. Trends in annual moisture depletion and recharge were similar in both studies. However, in Troendle's study, soil moisture contents on both the forested and barren areas were identical during the dormant season following moisture recharge that occurred in December.

The increased soil depth and organic-matter content at the fill position were attributed to deposition of soil from the cut portion of the road prism (Fig. 11). Although the fill positions had greater soil depth and higher organic-matter content, soil-moisture content and bulk density at depths up to 12 inches at this position were similar to those at other road positions. Soil-moisture contents at deeper depths, e.g., 12 to 24 inches, probably were higher on the fill portion of the roadbed. Both the litter layer of the original soil and the recently deposited soil were visible in 1998 when soil samples were collected. Since most of the additional organic matter has not had time to completely break down and become incorporated into the fill soil profile, its full effect on growth may not be reflected in current growth measurements.

Our results indicate that the fill portion of newly constructed skidroads in Appalachian clearcuts provides suitable planting sites for northern red oak. Although bulk density is elevated slightly on road fills, survival and height growth were comparable to those in the off-road positions, suggesting few major limitations to the use of road fills for enrichment planting. There are several advantages to using skidroads for enrichment plantings. Vegetation management requirements are reduced because fresh roadbeds provide an environment that is relatively free of competition for several years. Also, roads provide ready access to seedlings planted on them so seedlings can be located, tree shelters maintained, and vegetation managed around them if necessary. Confining plantings to road fills still will allow the use of skidroads by ATV's, a common mode of travel on them in the Appalachians. A major limitation to using skidroads as planting sites is damage by black bears. Bears travel on skidroads and often damage tree shelters and the seedlings within them. Nonetheless, in selected areas, the use of skidroads as planting sites provides land managers with a regeneration technique that can facilitate enrichment plantings in Appalachian clearcuts.

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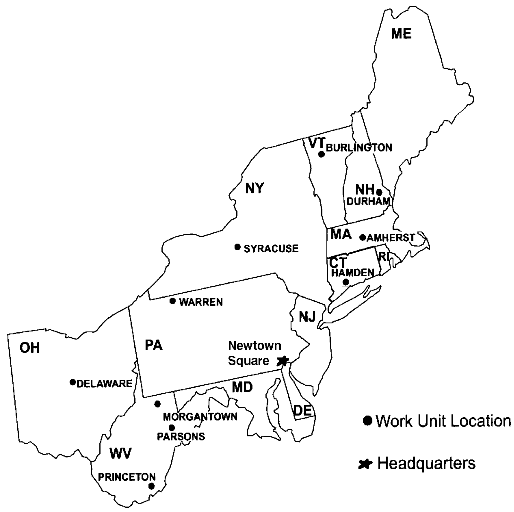
Artificial regeneration of northern red oak in Appalachian clearcuts on mesic sites is hindered by accessibility and competition from developing vegetation. The use of skidroads as a planting medium was evaluated on two clearcuts with contrasting aspects in north central West Virginia. Stratified acorns were planted in tree shelters at three positions (cut, middle, fill) on the roadbed and one position (off road) adjacent to the roadbed. Height growth, percent survival, competitive status, and potential crop trees (PCT) were measured after eight growing seasons. Soil parameters also were measured. Height growth was greatest on the off-road and fill positions. The overall height difference (1.5 feet) between off-road and fill positions was less than expected from measurements of soil bulk density and moisture content. Reduced competition improved the competitive status of all roadbed trees, though competitor trees on average were 4.4 feet taller than PCTs after 8 years.

KEY WORDS: artificial regeneration; road position; herbicide release; soil moisture; soil bulk density



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