Growth of Eastern White Pine *(Pinus strobus* L.) Related to Forest Floor Consumption by Prescribed Fire in the Southern Appalachians

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ABSTRACT: *Chainsaw felling, burning, and planting of eastern white pine* (Pinus strobus *L.) have been prescribed on degraded pine/hardwood stands in the Southern Appalachians to improve overstory composition and productivity. The desired future condition of the overstory is a productive pine/hardwood mixture, with white pine, which is resistant to southern pine beetle* (Dendroctonus frontalis*), as the dominant pine. We evaluated the growth of white pine planted after fell-and-burn treatments through eight growing seasons after planting on three sites that differed in their fire characteristics and carbon and nitrogen losses. The three sites (JE, JW, and DD) differed in heat penetration and forest floor consumption. Although very little consumption of the Oe+Oa humus layer occurred during burning, consumption of the Oi litter layer was 94%, 94%, and 63% at JE, JW, and DD, respectively. Corresponding to the forest floor layer consumption (Oi and Oe+Oa combined), 46% of forest floor N was lost at JE, 45% of forest floor N was lost at JW, and less than 0.1% of the forest floor N was lost at DD. Biomass and density of woody competitor species were not significantly related to white pine size or growth. By the eighth growing season, no differences in white pine size or growth were detected between JE and JW, but DD had significantly smaller white pine trees. The size difference between DD and the other two sites was attributed to the replanting of seedlings at DD in 1992. However, relative growth rate (RGR) was significantly higher on DD in 1998 than the other two sites. Eight growing seasons after planting, white pine growth was negatively related to percent Oi layer consumed on the JE and JW sites. We also found significant relationships between white pine RGR and percent Oi consumed using data from all three sites. Although fire severity had a long-term effect on pine growth, fire severity was considered low overall on these sites because there were limited losses from the forest floor Oe+Oa layer. However, white pine increment and RGR were significantly related to percent forest floor Oi mass and N loss. This loss of site N capital could have a significant negative effect on growth of planted white pine over the long term. South. J. Appl. For. 26(1):18–25.*

Key Words: Mountain laurel, *Kalmia latifolia*, evergreen shrubs, dry ridges, fell and burn.

In the Southern Appalachian region, mixed pine/oak forest types on dry ridges (primarily composed of pitch pine *(Pinus rigida* Mill.) and chestnut oak (*Quercus prinus* L.) in the overstory and mountain laurel *(Kalmia latifolia* L.) in the understory have depended on fires for their maintenance (Barden and Woods 1976, Harmon 1982, Williams et al. 1990). More recently, fire exclusion in combination with the selective removal of high-quality trees has changed the natural structure and composition of many mixed pine/oak forests (Van Lear and Waldrop 1989, Harrod et al. 1998). Substantial drought-related southern pine beetle *(Dendroctonus frontalis* Zimm.) infestations contributed to further degradation of these forests (Smith 1991). The result has been a significant increase in the dominance and area of mountain laurel, which forms dense stands on upper, drier slopes and competes with woody and herbaceous vegetation.

In 1993, a series of papers (Swift et al. 1993, Clinton et al. 1993, Vose and Swank 1993, Knoepp and Swank 1993, Elliott and Vose 1993) presented the first-year results from a fell-and-burn treatment prescribed on xeric mountain sites in the Southern Appalachians. The treatment consisted of: (1) chainsaw-felling of all woody vegetation, (2) allowing stumps to sprout, (3) burning the sites with a high-intensity, low-

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severity fire, and (4) planting eastern white pine *(Pinus strobus* L.) at low density to provide a mixed-species stand. The purpose of the burning treatment was to restore these degraded sites to a more diverse and productive mixed pine/hardwood community. The silvicultural objective was to increase overall productivity of commercial species (i.e., white pine has a faster growth rate than pitch pine even on these dry sites) and reduce susceptibility to insect damage (i.e., white pine is more resistant to southern pine beetle than pitch pine).

White pine growth during early stand development has been documented for the first and second years following planting, where diameter growth and seedling physiology were related to biomass of all competitors (Elliott and Vose 1993) and the competitive environment was evaluated using individual pine seedling models (Elliott and Vose 1995). This article presents the survival and growth of white pine trees 8 yr after planting, on three fell-and-burn sites that differed in their fire characteristics and carbon (C) and nitrogen (N) losses. We hypothesized that average white pine growth across these three sites could be affected by regrowth of potential competitors, particularly fast-growing sprouts, and the variation in fire severity. If losses and subsequent recovery of C and N pools after fire are a function of fire severity (Clinton et al. 1995), then fire severity would have a negative impact on the potential growth of planted white pine by reducing N pools and fluxes. Our objectives were to: (1) compare white pine size and growth among sites differing in their fire characteristics and subsequent C and N losses; and (2) relate white pine growth and relative growth rate (RGR) to woody competitor biomass and forest floor consumption.

Methods

Site descriptions

Three sites, approximately 5.25 ha each, were chosen from areas previously selected for prescribed burning in the Land Management Plan for the Wayah Ranger District (USDA Forest Service, Nantahala National Forest, North Carolina). Two sites, Jacob Branch East (JE) and Jacob Branch West (JW), were within 0.4 km of each other, and the third site, Devil's Den (DD), was approximately 20 km from the others. All sites were within the Blue Ridge physiographic province of the Southern Appalachians (latitude 35°12′N, longitude 83°24′W). JE and DD had southwestern aspects, and JW had a western aspect. Midslope elevations on JE and JW are approximately 755 m. Elevation at DD is approximately 1040 m. Soils are in the Cowee-Evard complex, which includes fine-loamy, mixed, mesic Typic Hapludults with only scattered rock outcrops and a clay loam layer at a depth of about 30-60 cm. The pretreatment overstory vegetation was mainly scattered pitch pine, scarlet oak (*Q. coccinea* Muenchh.), and chestnut oak. Overstory basal areas ranged from 9 m^2/ha to 19 m^2/ha. The shrub understory, which was dominated by mountain laurel, ranged in basal area from 18 m^2/ha to 35 m^2/ha. Vose and Swank (1993) described pretreatment stand structure and biomass in detail. Fire characteristics (Swift et al. 1993); and mass, C, and N losses (Vose and Swank 1993) are provided in Table 1.

Experimental design

In the summer of 1989, five 0.05 ha plots (15 x 33 m) were established at each site to study a variety of ecosystem processes (Swift et al. 1993), including those of interest in this study. Plots were located along steeply sloping (35–45% slope) midslope positions. Between late July and late August 1990, all sites were cut (including understory woody species) with no merchantable products removed. The three sites were burned on separate days from September 18 to 21, 1990 (Swift et al. 1993). Consumption of dry foliage, loose forest floor litter, and fine woody material was complete except along the shaded margins of the cut area (well outside of the established plots). In the upper centers of the three sites, the fire consumed or reduced most of the small woody material

Table 1. Characteristics of the three sites, Jacobs East (JE), Jacobs West (JW), and Devil's Den (DD) after the fell and burn treatment: fire characteristics taken from Swift et al. (1993); mass, carbon (C), and nitrogen (N) losses taken from Vose and Swank (1993). Values in parentheses for heat penetration and mean peak flame temperature are standard errors; values in parentheses for mass, carbon, and nitrogen losses are percentages.

	Site		
	JE	JW	DD
Fire characteristics			
Fuel loading (Mg/ha)	200.7	138.1	136.1
Fuel consumption (Mg/ha)	124.7	67.3	70.5
Heat penetration @ 60°C (mm)	45 (2.4)	37(1.7)	44 (2.1)
Mean peak flame temperature (°C)	812 (46)	694 (33)	630 (78)
Total aboveground mass, carbon, and nitrogen losses			
Mass (Mg/ha)	129.7 (58%)	86.3 (48%)	62.2 (49%)
Carbon (Mg/ha)	61.2 (58%)	42.2 (50%)	29.3 (51%)
Nitrogen (kg/ha)	480 (61%)	376 (58%)	193 (33%)
Forest floor mass loss			
Oi layer (Mg/ha)	11.8 (94%)	10.1 (94%)	6.0 (63%)
Oe + Oa layer (Mg/ha)	3.8 (14%)	2.5 (12%)	0.6 (3%)
Forest floor nitrogen loss			
Oi layer (kg/ha)	96.4 (95%)	93.3 (92%)	46.3 (56%)
Oe + Oa layer (kg/ha)	26.6 (11%)	40.5 (20%)	–45.0 (-20%)

(<8 cm diameter). Early the next spring (February and March 1991), 2-yr-old bareroot white pine seedlings were planted at 5 x 5 m spacing on the burned sites. JE and JW were planted in late February, and DD was planted in late March. Due to the high mortality at DD, an additional 400 seedlings/ha were planted in February 1992 to provide adequate stocking of this site. Although these sites are considered xeric, white pine was planted because of higher growth rates and increased resistance to pine beetle relative to other pine species typical of these sites (e.g., pitch pine, Virginia pine *(P. virginiana* Mill.), or shortleaf pine *(P. echinata* Mill.)).

Woody biomass was sampled in four 3.0 x 3.0 m subplots within each 0.05 ha plot on each site. All woody stems were identified to species and measured for basal diameter using calipers. Due to the clumped nature and prolific sprouting exhibited by mountain laurel, clump area estimates were determined based on the average of two crown diameter measurements and converted to biomass using allometric equations developed specifically for mountain laurel on these sites (Elliott and Clinton 1993). All other woody species were assigned to one of eight categories: red oaks (*Q. rubra* L., *Q. velutina* Lam., *Q. coccinea* Muenchh.), white oaks *(Q. alba* L., *Q. prinus* L.), sourwood (*Oxydendrum arboreum* [L.] DC.), red maple *(Acer rubrum* L.), yellow pines, serviceberry *(Amelanchier arbor ea* Michaux), black locust *(Robinia pseudoacacia* L.), and "others." Estimates of woody biomass were made using allometric equations of Boring and Swank (1986), Clark and Schroeder (1986), and site- and species-specific equations of Elliott and Clinton (1993).

We measured diameter at ground level and height of each white pine seedling soon after planting (early April 1991) and at the end of the 1991, 1992, and 1998 growing seasons. We used the product of stem diameter squared and stem height (D^2H) as a surrogate for total tree volume. For each year, we calculated increment in diameter, height and D^2H growth as the difference between beginning-of-year and end-of-year measurements. We calculated relative growth rate (*RGR*) for each period between measurements because *RGR* expresses the rate of tree growth independent of size (Evans 1972). RGR was calculated as:

$$RGR_D = (\ln D_2 - \ln D_1)\ (t_2 - t_1)$$

where D = diameter and t = time in years, and

$$RGR_H = (\ln H_2 - \ln H_1)\ (t_2 - t_1)$$

where H = height, and

$$RGR_{D2H} = (\ln D^2H_2 - \ln D^2H_1)\ (t_2 - t_1)$$

where D^2H = diameter squared x height.

Statistical Analyses

Analysis of variance (ANOVA) was used to determine significant differences among sites for white pine growth. If a significant ANOVA was found, then a Ryan-Einot-Gabriel-Welsch (REGWQ) multiple range test was conducted (PROC GLM, SAS Institute Inc. 1996).

We chose to use the 6 yr growth period from 1993 to end of the growing season in 1998 in all regression analyses, because this growth period followed successful seedling establishment. White pine diameter, height, and D^2H growth and relative growth rates averaged at the plot level were related to aboveground biomass of woody species (total biomass and biomass of species groups (red maple, oaks, evergreen, black locust, others)) and percent forest floor mass and N consumption using regression analysis (PROC REG, SAS Institute Inc. 1996). Heat penetration into the soil and consumption of forest floor litter (Oi) and humus (Oe+Oa) are both measures of fire severity (Wells et al. 1979, Simard 1991). However, because heat penetration was not measured at the plot level, and forest floor consumption was measured at the plot level, we used percent consumption of the forest floor Oi layer and Oe+Oa layer in regression analysis to explain the variation in average white pine growth and *RGR* per plot across the sites. After examining the scatterplots of average white pine RGR_D, RGR_H, and RGR_{D2H} per plot against forest floor and N mass losses per plot, we tested for outliers using influence diagnostics in PROC REG (SAS Institute Inc. 1996). The *R*-student statistic was used to determine if an individual data value was a high influence point (HIP) on the regression line. The *R*-student statistic allows a formal mechanism for detection of outliers through hypothesis testing (Myers 1990).

Results and Discussion

The first year after planting, mortality of planted white pine varied among the three sites (JE = 38%, JW = 14%, and DD = 69%). Higher mortality of white pine seedlings at DD was attributed to planting later in the season resulting in poor establishment of root-soil contact (Burdett et al. 1983, Burdett 1990), and to infestation of pine pales weevil (*Hylobius pales* Herbst) (Elliott et al., personal observation). Accounting for the survival of seedlings from the initial planting in 1991, and the low mortality (15%) from the second planting, white pine density in 1998 at DD was 600 stems/ha (vs. 120 stems/ha without replanting). At the other two sites, white pine stand density was 300 and 428 stems/ha for JE and JW, respectively. The first and second growing seasons after planting, no significant differences in white pine size or growth emerged between the JE and JW sites (Table 2). By the eighth growing season, no differences were detected between JE and JW, but DD had significantly smaller white pine trees (Table 2). The size difference between DD and the other two sites was attributed to the replanting of seedlings in 1992. However, RGR_D, RGR_H, and RGR_{D2H} were significantly higher on DD in 1998 than the other two sites (Table 2), perhaps because of the younger age of seedlings at DD.

Pine Growth Response to Competitor Woody Biomass

After eight growing seasons, aboveground biomass of woody species other than white pine was 8.9 Mg/ha, 11.8 Mg/ha, and 8.2 Mg/ha for JE, JW, and DD, respectively. The range in plot values was 4.3 Mg/ha to 18.1 Mg/ha across the three sites. However, average white pine size, growth, and mortality were not significantly related to biomass and density of woody species (total and by groups such as oaks, maple, evergreen). In an earlier study on these sites, Elliott

Table 2. Diameter, height, and D2H growth of white pine (*Pinus strobus* L.) planted on fell and burn sites in the southern Appalachians; first growing season (1991), second growing season (1992), and eighth growing season (1998) after planting for Jacobs East (JE), Jacobs West (JW), and Devil's Den (DD) sites.

	Years after planting							
	1		2			8		
	JE	JW	JE	JW	DD	JE	JW	DD
Final diameter (cm)	0.64 (0.01)	0.60 (0.01)	0.97 (0.06) a†	0.99 (0.06) a	0.50 (0.01) b	9.09 (0.50) a	8.15 (0.33) a	6.52 (0.34) b
Diameter increment (cm/yr)*	0.20 (0.02)	0.16 (0.01)	0.33 (0.02) a	0.39 (0.05) a	—	1.35 (0.08) a	1.19 (0.05) a	1.00 (0.06) b
Relative diameter growth*	0.17 (0.02)	0.14 (0.01)	0.20 (0.01) a	0.22 (0.02) a	—	0.16 (0.01) a	0.15 (0.01) a	0.19 (0.01) b
Final height (cm)	25.1 (1.0)	26.0 (0.2)	43.3 (3.0) a	48.8 (1.6) a	38.8 (1.4) b	464 (26) a	471 (14) a	371 (14) b
Height increment (cm/yr)*	11.3 (0.6)	10.8 (0.5)	18.2 (2.4) a	22.8 (1.6) a	—	70.1 (4.2) a	70.4 (2.2) a	57.1 (2.3) b
Relative height growth rate*	0.27 (0.02)	0.24 (0.01)	0.25 (0.01) a	0.28 (0.01) a	—	0.18 (0.01) a	0.17 (0.002) a	0.19 (0.01)b
Final D^2H (cm^3)	11.3 (1.02)	10.4 (0.51)	52.9 (8.3) a	61.7 (9.0) a	9.9 (1.1) b	49,490 (5,350) a	39,737 (3,830) a	23,413 (2,814) b
D^2H increment (cm^3/yr)*	8.36 (0.90)	7.19 (0.52)	41.6 (7.4) a	51.2 (8.5) a	—	8,239 (891) a	6,612 (638) a	3,900 (469) b
Relative D^2H growth rate*	0.62 (0.05)	0.51 (0.03)	0.64 (0.02) a	0.71 (0.05) a	—	0.50 (0.02) a	0.48 (0.01) a	0.57 (0.02) b

* For the eighth year after planting, annual increment and relative growth rate are based on the 6 yr from 1993 through the end of the growing season 1998.

† Within years, values in rows followed by different letters are significant at $P < 0.05$.

and Vose (1995) found white pine diameter growth was inversely related to competitor biomass using individual seedling-based models; however, the explanatory power of these models was low. In a 14-yr-old white pine stand, Clinton et al. (1997) found significant relationships using individual tree measurements of white pine growth and distance-dependent and distance-independent competition indices (Clinton et al. 1997). Thus, in our study of the 8-yr-old stand, it is possible that some individual white pine trees experienced competition, but overall competitor biomass does not appear to restrict average pine growth at the plot level. In addition, by the fifth growing season white pine trees had overtopped hardwood competitors on these sites (Elliott et al., personal observation), similar to findings for shortleaf pine and loblolly pine (*P. taeda* L.) on fell-and-burn treatments in South Carolina (Waldrop et al. 1989).

Pine Growth Response to Fire Severity

Fire severity was assessed by heat penetration into the forest floor and mineral soil (Swift et al. 1993) and by the amount of forest floor layer consumed (Vose and Swank 1993). The three sites differed in heat penetration and forest floor consumption (Table 1). Although little consumption of the Oe+Oa layer occurred during burning, consumption of the Oi layer was 94%, 94%, and 63% at JE, JW, and DD, respectively (Table 1). Total aboveground N loss ranged from 193 to 480 kg/ha on these sites (Table 1) with DD having the lowest total aboveground mass, carbon, and nitrogen lost of the three sites. Corresponding to the forest floor layer consumption (Oi and Oe+Oa combined), 46% of forest floor N was lost at JE, 45% of forest floor N was lost at JW, and less than 0.1% of the forest floor N was lost at DD (Vose and Swank 1993). Forest floor N loss at DD was minimal because the Oe + Oa layer gained N after burning due to the downward movement of N from the Oi layer (Table 1). Knoepp and Swank (1993) found that soil ammonium (NH_4^+) response to treatment followed the same order as the fire severity; i.e., JE>JW>DD. Increases in the NH_4^+ levels after the fire were attributed to volatilization of organic N from the soil surface and its condensation after downward movement into cooler soil horizons (Rauch 1991). However, this increased soil NH_4^+ was short-lived (see Knoepp and Swank 1993), similar to results from other studies where soil NH_4^+ levels were increased for less than 2 yr after burning treatments (Phillips and Goh 1985, Covington and Sackett 1986, Kovacic et al. 1986, Schoch and Binkley 1986, White 1986). The loss of soil N pool input sources, particularly the forest floor, could have a long-term effect on N availability (Vose and Swank 1993, Clinton et al. 1996) and subsequent pine growth.

Overall, fire severity was considered low on these sites based on criteria from Waldrop and Brose (1999); i.e., the litter layer (Oi layer) was removed but the duff layer (Oe+Oa layers) remained intact and little soil was exposed. However, eight growing seasons after planting, we found significant negative relationships between white pine growth and percent Oi layer consumed (Figures 1a, 1b, and 1c) on the JE and JW sites. Percent Oi layer consumed explained 46% of the variation in white pine

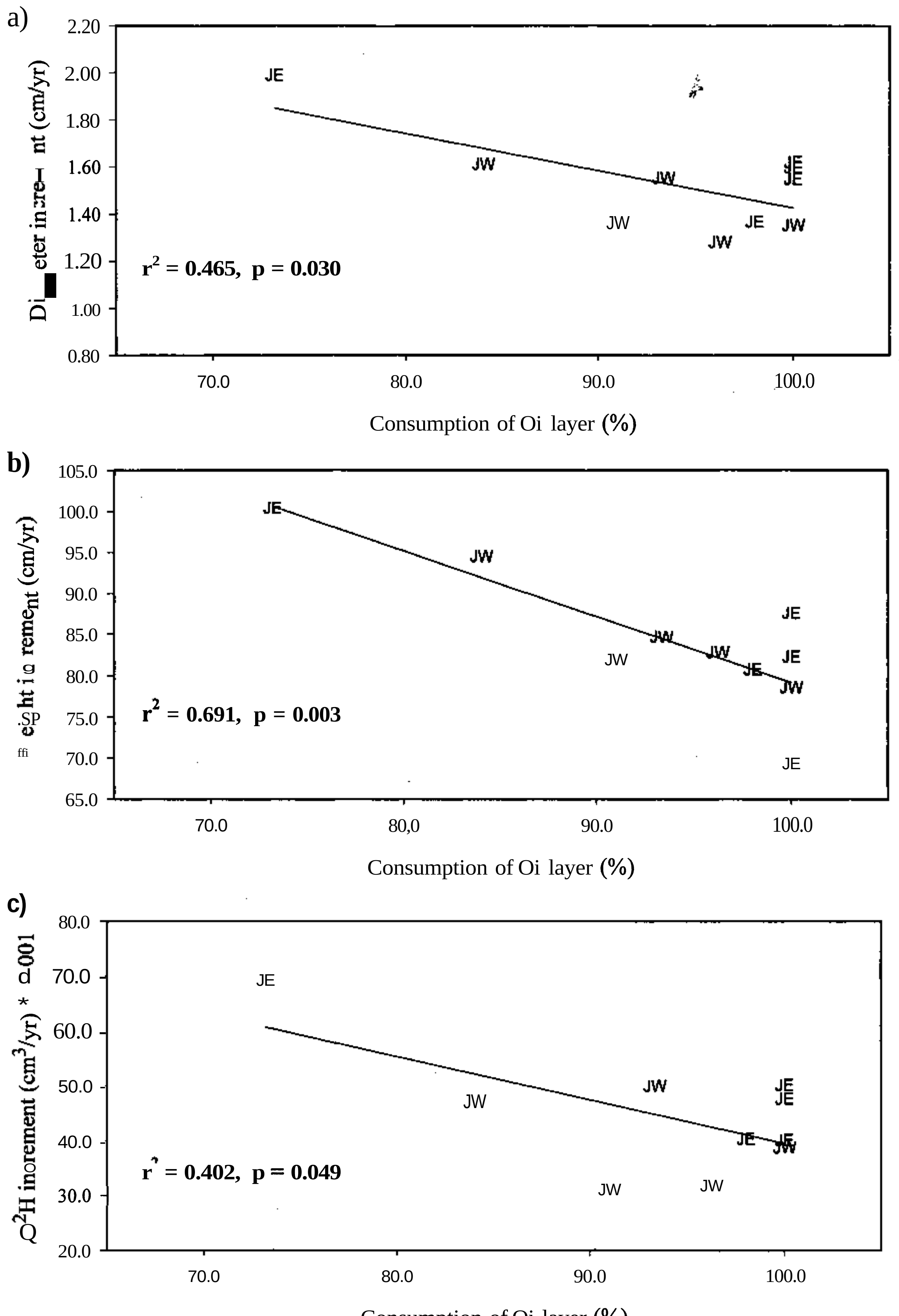

Figure 1. Relationship between eastern white pine *(Pinus strobus* L.) growth with percent consumption of the forest floor Oi layer the eighth growing season (1998) after planting on two fell-and-burn sites [Jacobs Branch East (JE) and Jacobs Branch West (JW)] in the Southern Appalachians: (a) diameter increment (b) height increment, and (c) diameter squared times height (*D^2H*) increment.

average diameter growth, 69% of the variation in average height growth, and 40% of the variation in average D^2H growth. We also found a significant negative relationship between white pine *RGR* and percent Oi consumed using data from all three sites (Figures 2a, 2b, 2c). One data point (representing a plot on DD at the upper slope, near the unburned edge) was determined to be an outlier (i.e., high influence point; HIP) based on the *R*-student statistic (Myers 1990). With removal of this data point from the regression analyses, percent Oi consumed explained 66% of the variation in RGR_D, 57% of the variation in RGR_H, and 65% for RGR_{D2H}. This HIP (Figures 2a, 2b, and 2c) could suggest a curvilinear relationship (Myers 1990) between pine *RGR* and percent Oi consumed; however, more data at the lower level of percent Oi consumed would be necessary to verify this pattern. A curvilinear relationship, similar to a bell-shaped curve might be an expected response, since at low fire severity hardwood competition might reduce growth, while at high fire severity, N losses could reduce N supply and subsequent site productivity. The optimal treatment requires a balance between reducing competition while retaining site N. Relationships between white pine *RGR* and percent N mass lost in the Oi layer (OiN) followed the same pattern as percent Oi consumed. For example, significant ($P < 0.001$) coefficients of determination were: $r^2 = 0.636$ for RGR_D vs. OiN; $r^2 = 0.597$ for RGR_H vs. OiN; and $r^2 = 0.639$ for RGR_{D2H} vs. OiN.

Fire severity with a corresponding loss in N pools had a significant negative effect on white pine growth after eight growing seasons. On these same sites, 2 yr post-treatment, Clinton et al. (1996) found that site recovery was a function of fire severity and the capacity for site-nutrient retention through plant uptake. Vose and Swank (1993) reported increased N in the Oe+Oa layers immediately following fire. However, N concentrations tended to decline on all sites in the Oi and Oe+Oa layers by year 2 (Clinton et al. 1996). Even though mass in the Oe+Oa layer was unchanged, the decline in N concentrations resulted in a decline in total N pools by year 2. Elliott and Vose (1993) reported that both N and light were the dominant factors limiting photosynthesis and diameter growth of white pine seedlings the first growing season after planting on these burned sites.

Conclusions

For the past 15–20 yr, prescribed fire has been applied as a management tool in pine/hardwood ecosystems using an approach called the fell-and-burn technique. The objective is to increase overall productivity of commercial species and reduce susceptibility to insect damage by planting white pine after burning. This practice changes the current structure and function of the ecosystem to achieve silviculturally based objectives. In addition, the prescribed burning increased the health and sustainability of the ecosystem by increasing diversity (Clinton and Vose 2000) and productivity (Clinton et al. 1993, Elliott and Vose 1993), stimulating N cycling (Knoepp and Swank 1993), and reducing fuel loading (Vose and Swank 1993). The only potential negative impact is loss of total aboveground growth and forest floor N (Vose 2000).

Our study suggests that fell-and-burn treatments were effective in reducing competition to white pine, since no significant relationships between white pine growth or mortality and woody species density or biomass were found. However, fire severity had a long-term negative effect on pine growth. Fire severity was low overall on these sites since the fire prescription limited losses of the forest floor Oe+Oa layer. Maintenance of the Oe+Oa layers is critical for site nutrient retention and soil stabilization. However, white pine growth and relative growth rates were negatively related to percent consumption of the forest floor Oi layer mass and N. Forest floor N in the Oi and Oe+Oa layers was significantly reduced 2 yr after the fell-and-burn treatments; this loss of site N capital could have a significant negative effect on growth of planted white pine in the long term. A balance between reducing competition and retaining or improving site N would be an optimal fire treatment for these pine/hardwood sites. Managers need to understand both short- and long-term effects on the whole system, not just narrowly defined silvicultural objectives, and consider the role of fire in ecosystem health and sustainability. This knowledge could be applied to modify burning prescriptions to minimize N losses but still improve the condition of degraded pine/hardwood stands (Vose et al. 1997, Elliott et al. 1999). For example, a late winter/early spring burn, conducted before leaf-out (before plant nutrient uptake begins) and after litter decomposition has returned a proportion of leaf nutrient capital to the Oe+Oa layer and mineral soil, may be better than a late summer burn. In addition, planting another species of pine on these sites after prescribed burning may be a future consideration. For example, shortleaf pine is a commercial species which is adapted to drier site conditions and because of its thicker bark is more fire tolerant than white pine (Burns and Honkala 1990); however, this species is susceptible to pine bark beetle attack and has a slower growth rate than white pine even on these dry sites.

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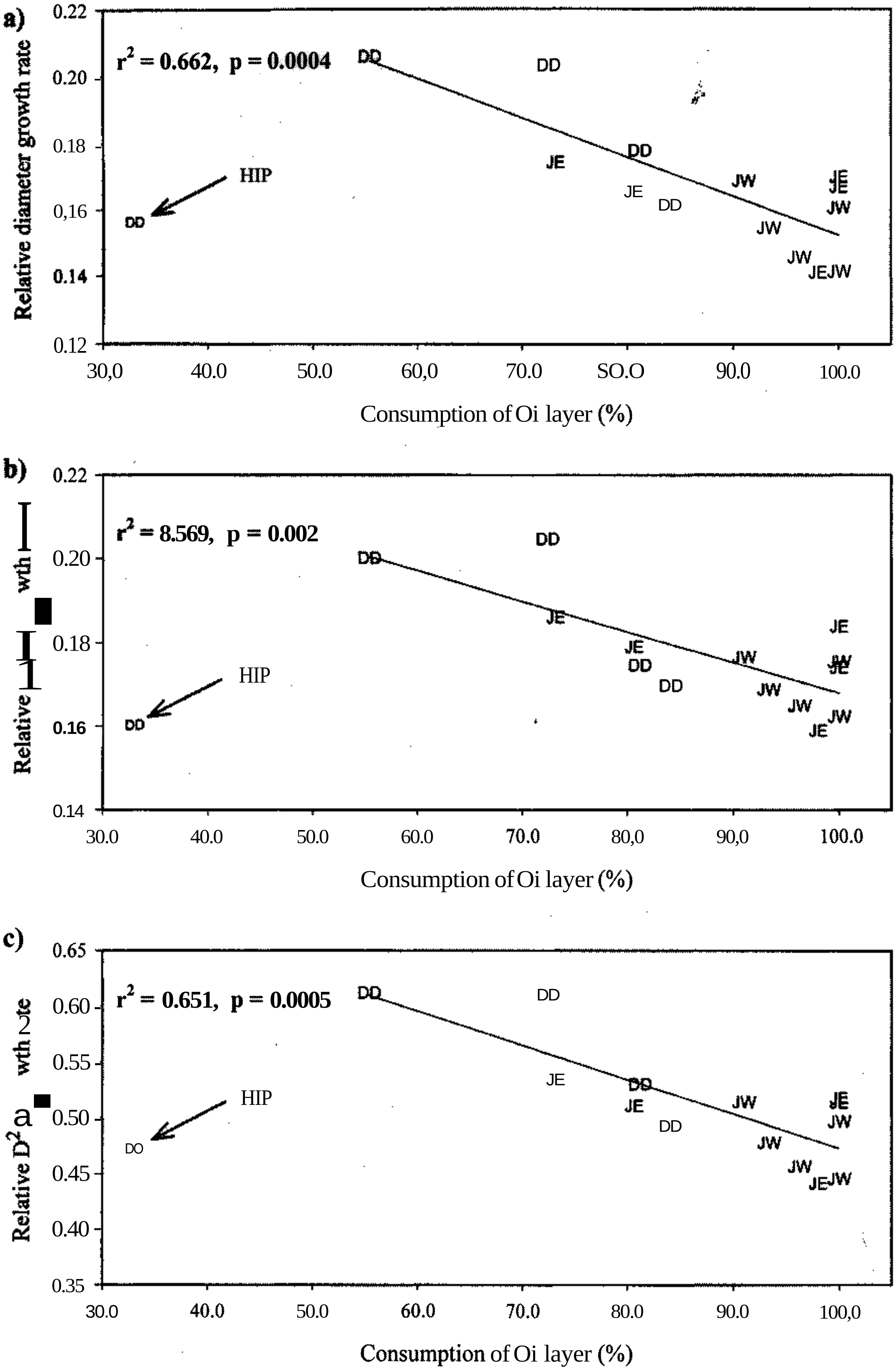

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