EFFECT OF SITE FACTORS ON GROWTH RESPONSE OF 9 TO 15-YEAR-OLD SLASH PINE PLANTATIONS FOLLOWING UNDERSTORY VEGETATION REMOVAL

by

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INTRODUCTION

The control of competing vegetation in southern pine plantations has become one of the primary research interests among forest landowners in the southeast. The main thrust of competing vegetation research has been to determine the effects of weed control on growth and survival during the first few years after plantation establishment. As a result of these investigations, extensive literature addressing both the early growth benefits of controlling competition in newly planted southern pine plantations and the effectiveness of different control methods is available to forest managers. However, little information is available regarding the effect of removing understory vegetation from plantations which have achieved crown closure.

Those studies which did assess the benefits of understory vegetation control in southern pine stands were not replicated over a large region, and report conflicting results. Overstory pine growth responded to understory removal in some of these studies (Bower and Ferguson 1968, Grano 1970, Clason 1984), but failed to respond in others (Cain 1985, Lange 1951, McClay 1955, Russell 1961).

It is certain that the numerous noncommercial hardwood and herbaceous plants occurring in most site-prepared, crown closed slash pine plantations consume site resources. But, based on the contradictory results in the above studies, it is questionable whether this consumption is at the expense of the overstory pine and thus, can be considered competition.

In pine plantations which have achieved crown closure it seems reasonable to speculate that if competition with understory competition does exist, it is primarily for soil water, nutrients, and rooting space, rather than for light. Amounts of these resources available to plants varies from site to site, with the result that the effect of understory vegetation consumption of these resources on overstory pine growth should also vary from site to site assuming a similar understory composition.

In 1976 the Plantation Management Research Cooperative (PMRC) at the University of Georgia initiated an understory competing vegetation study in 9 to 15-year-old site-prepared slash pine plantations. Thirty-two study sites were installed in plantations with throughout the Lower Coastal Plain of Georgia and north Florida and were equally divided across four soil drainage class groups. The results after ten years of control concur with the above hypothesis by revealing a positive average response in overstory growth with large differences in response from site to site (Oppenheimer *et al.* 1988). However, the four soil drainage groups did not help explain this variability.

Although the four soil drainage groups did not significantly explain varying growth responses, this does not completely preclude the possibility that reduced growth due to understory competing vegetation is related to soil water. The drainage groups used in the PMRC study may have been too broad to accurately describe the important soil water properties within study sites. Similarly, since soil drainage classes are based on water table depths, they provide little information concerning possible soil fertility problems which could effect the impact of understory vegetation competition on overstory pine growth. Therefore an examination of more specific soil characteristics was made at each of the 32 PMRC study sites in an attempt to help interpret the observed varying growth responses. This paper reports the results of the soil investigation.

DESCRIPTION AND DESIGN OF STUDY

Paired permanent plots were established in 32 existing 9 to 15-year-old site-prepared slash pine plantations located in the Lower Coastal Plain of Georgia and north Florida during the winter of 1976. Thirty-one of the 32 pairs were in the 9 to 12 year age range. The geographical location of these paired plots (study locations) are shown in Figure 1. Only plantations with a considerable amount of understory vegetation were considered for selection.

Plot location within a plantation was selected on the basis of uniformity of soil morphology, quantity and composition of understory vegetation, and the minimization of wildlings within the plots. Study sites were equally distributed among four soil drainage groups defined in terms of the USDA Soil Conservation Service classifications as:

1) Very poorly and poorly drained (VP & P)

2) Somewhat poorly and moderately well drained (SP & MW)

3) Well drained (W)

4) Somewhat excessively and excessively drained (SE & E).

Paired plots, each seven rows by 100 feet were installed at each selected site. Plots were paired so that basal area per acre differed by less than 10 square feet between plots of a pair, and site index (base age 25) varied by less than five feet. One randomly selected member of each pair was left unaltered, while in the other plot all understory vegetation was cut at ground level. In April and in May of 1976 all new growth and sprouts were sprayed with glyphosate herbicide at manufacturer's recommended concentrations. Those sprouts not eliminated by this spray treatment were sprayed shortly afterwards with paraquat herbicide at recommended concentrations. Complete control of understory vegetation was maintained by annual spot spraying where necessary. Overstory pines were carefully protected from all herbicide applications.

In each plot the interior three rows by 70 feet (approximately 0.04 acres) served as the measurement plot, thus allowing for a 2-row buffer on each side and a 15 foot buffer at each end.

All overstory pines within the three row by 70 foot measurement plots received numbered tags at the time of initial (1976) treatment Tagged trees were measured for dbh with a diameter tape to the neare 0.1 inch, and for total height with a hypsometer to the nearest foot

Remeasurements of surviving tagged trees were made in the winter of 1978, 1980, 1982, 1984, and 1986. Individual tree stem volumes were calculated for each occasion using volume equations developed by Pienaar *et al.* (1988). The 1986 average height of all dominants and codominants present in each control (untreated) plot was used in the Pienaar *et al.* (1988) height growth equation to determine each location's site index (base age 25).

At the time of initial (1976) treatment, stand basal area and density in the measurement plots ranged from 50 to 100 square feet per acre and from just under 400 to 1100 trees per acre, respectively. The initial average overstory plot height was between 15 and 37 feet, and initial total plot volume varied from 260 to 2400 cubic feet per acre. The range of site index (base age 25) was from 40 to 80 feet with 23 plot pairs being between 50 and 70.

A complete soil profile description to a depth of 80 inches was compiled at each study location using the guidelines and terminology presented in Chapter Four of the USDA Soil Survey Manual (Soil Survey Staff 1951).

Table 1 contains a list of the understory vegetation species which were commonly present at the study locations during the time of initial treatment. While many of these species can occur on a variety of soil drainage conditions, most tend to be limited to two or three of the Soil Conservation Service soil drainage classes as indicated in Table 1.

Table 1. Primary understory species present at time of initial treatment, and soil drainage classes they most commonly occupied.

Species	Common name	Soil Drainage Class
Hardwoods		
Acer rubrum	Red maple	SP, MW
Cornus florida	Flowering dogwood	MW, W
Cyrilla racemiflora	Black titi	VP, P
Diospyros virginiana	Persimmon	SP, MW, W
Gordonia lasianthus	Loblolly-bay	VP, P
Hypericum fasciculatum	St. John's wort	VP, P, SP
Ilex cassine	Dahoon	VP, P, SP
Ilex glabra	Gallberry	VP, P, SP
Ilex vomitoria	Yaupon	SP, MW, W
Liquidambar styraciflue	Sweetgum	SP, MW, W
Magnolia virginiana	Sweetbay	VP, P
Myrica cerifera	Wax myrtle	P, SP
Nyssa sylvatica	Blackgum	P, SP
Persea borbonia	Red bay	VP, P, SP
Quercus chapmanii	Chapman oak	MW, W, SE
Quercus incana	Bluejack oak	W, SE, E
Quercus laevis	Turkey oak	W, SE, E
Quercus laurifolia	Laurel oak	SP, MW, W
Quercus nigra	Water oak	P, SP
Smilax spp.	Greenbrier	SP, MW, W
Vaccinium arboreum	Sparkleberry	P, SP, MW
Viburnum obovatum	Walter's viburnum	VP, P, SP
Palms		
Sabal minor	Needle palm	P, SP, MW
Sabal palmetto	Cabbage palmetto	VP, P, SP
Serenoa repens	Saw palmatto	P, SP, MW
Herbaceous		
Andropogon spp.	Broomsedge	W, SE
Aristida stricta	Wire grass	W, SE, E
Arundinaria spp.	Switchcane	VP, P, SP
Eupatorium capillifolium	Dogfennel	P, SP, MW
Panicum spp.	Panicum	MW, W
Pteridium aquilinum	Brakenfern	SP, MW, W
Solidago spp.	Goldenrod	SP, MW, W
Xanthium spp.	Cocklebur	SP, MW, W

The primary soil orders occupying the Lower Coastal Plain are Spodosols, Ultisols, Inceptisols, and Entisols. Many great group divisions of these orders occurred across the 32 study locations. Table 2 lists these great groups along with their diagnostic horizons and possible soil drainage classes.

RESULTS

Since the locations of the paired plots were nested within soil drainage groups, a separate analysis of variance appropriate to a nested experimental design (Table 3) was performed on each of the following adjusted mean individual tree growth variables: height (ft), basal area (sq.ft per tree), total outside bark volume (cu.ft per tree), and merchantable inside bark volume to a four inch top diameter (cu.ft per tree). Basal area per tree growth was used as a substitute for diameter growth because it is less influenced by initial size. Adjusted net total and merchantable volume growth on a per acre basis were analyzed in the same manner as their respective individual tree growth variables. The factors included in the analysis of variance models were treatment, soil drainage group, location within soil drainage group, and the interaction of soil drainage group with treatment. Because the average individual tree growth variables had already been adjusted for initial differences between two plots of a pair, initial condition covariables were excluded from the model.

Results of the analysis of all four adjusted mean individual tree growth variables and both per acre growth variables indicate that in all cases treatment was highly significant (0.01 level), while soil drainage group and its interaction with treatment were found to be nonsignificant (0.05 level) after 10 growing seasons.

Table 2. Soil great groups and their frequency of occurrence at study locations.

Soil Order	Great Group	Diagnostic Horizons	Drainage Classes	Number of Locations
Spodosols	Haplaquods	Spodic	VP, P, SP	8
	Haplohumods	Spodic	P, SP, MW	3
Ultisols	Paleudults	Argillic	SP, MW, W	6
	Paleaquults	Argillic	VP, P, SP	3
	Albaquults	Argillic	VP, P, SP	2
Entisols	Quartzipsamments	none	SP, MW, W, SE, E	7
	Psammaquents	none	VP, P, SP	2
Inceptisols	Humaquepts	none	VP, P, SP	1

As expected, location within drainage group had a significant (0.01 level) effect on the four individual tree growth variables, but its interaction with treatment is unknown because location replicates were omitted from the study.

Adjusted individual tree and per acre growth means along with average initial (1976) size measurements are summarized in Table 4.

In order to determine if the removal of understory vegetation treatment had an effect on overstory mortality, the nested analysis of variance model was first fit to the number of trees per acre which did not survive the 1976-86 measurement period, and then to the percentage of initial trees which did not survive, and finally to the arcsine square root transformation of the percentage values. The results indicate that treatment did not significantly (0.05 level) effect any of these mortality variables. However the percentage of trees lost in the treatment plots was 25.2 percent greater than the percentage lost in control plots (Table 4). This difference in mortality may account for part of the discrepancy between the percentage values representing per tree volume growth response and those representing per acre volume growth response (Table 4).

Overall results from the PMRC study indicate that elimination of understory vegetation from 9 to 15-year-old site-prepared slash pine plantations in the Lower Coastal Plain of Georgia and north Florida can lead to a significant overstory growth response. Although treatment main effects were significant overall, there was a great deal of

Table 3. Analysis of variance format used for the analysis of all response variables.

Source	Factor	df	Expected Mean Square	F ratio
Treat	A fixed	1	MSA= $\sigma^2_{AC(B)} + bc\sigma^2_A$	MSA/MSE
Drain	B fixed	3	MSB= $\sigma^2_{AC(B)} + \sigma^2_{C(B)} + ac\sigma^2_B$	MSB/MSC(B)
Locat	C(B) random	28	MSC(B)= $\sigma^2_{AC(B)} + \sigma^2_{C(B)}$	MSC(B)/MSE
Treat*Drain	A*B	3	MSAB= $\sigma^2_{AC(B)} + \sigma^2_{AB}$	MSAB/MSE
Error	A*C(B)	28	MSE= $\sigma^2_{AC(B)}$	
Corrected Total		63		

Table 4. Average initial (1976) measurements and adjusted mean height, basal area, total and merchantable volume growth per tree and adjusted mean total and merchantable volume growth per acre along with average mortality for the period 1976-86.

Response Variable	Average Initial Measurement	Adjusted 10-year Growth		Increase Over Control	
		Control	Treated	Absolute	Percent
Height (ft)	28.4	20.3	21.8	1.5	7.4
Basal area (sq.ft)	0.107	0.110	0.131	0.021	19.1
Total volume (cu.ft)	1.80	3.87	4.49	0.62	16.0
Merch. volume (cu.ft)	0.74	2.98	3.50	0.52	17.4
Total volume (cu.ft)	1063.6	1972.6	2208.6	236.0	12.0
Merch. volume (cu.ft)	424.6	1525.3	1750.4	215.1	14.0
Mortality (percent)	617.1*	10.3	12.9	2.6	25.2

* Average initial density (trees/ac)

variability in the amount of adjusted growth response (i.e.treated minus control plot growth) observed between study locations. Remaining relative response variability after all experimental factors were accounted for was highest in the per acre total and merchantable volume growth analysis of variance models. Treated minus control plot total and merchantable volume growth per acre ranged from -984.5 to 1234.2 cubic feet and -464.9 to 1071.4 cubic feet, respectively. Average height and basal area per tree growth differences also varied widely ranging from -5.4 to 6.2 feet and -0.025 to 0.061 square feet, respectively. Because per tree basal area growth can be greatly influenced by stand density, and since per acre merchantable volume growth was relatively similar to per acre total volume growth, both of these response variables along with the two individual tree volume growth variables were excluded from further analysis. The two response variables with the largest range around zero, height and total volume per acre, were chosen as indicators in the attempts to explain the observed treatment response variability.

Using the collected soil profile descriptions, the 32 study locations were separated into the modified CRIFF (Cooperative In Forest Fertilization) soil groups defined in Table 5. These modified soil groups were obtained by dividing several of the original CRIFF groups presented by Fisher and Garbett (1980) into more specific groups.

An analysis of variance model which contained each location's growth response (i.e. treated minus control plot growth) as the dependent and the modified CRIFF soil groups as the independent variables revealed that these soil groups reduced the per acre total volume growth response variability by 70 percent, but only explained 37 percent of the variability in height growth response.

Table 6 contains the mean height and per acre volume growth response for each soil group. These responses are illustrated in Figure 2 which shows the mean 1986 height and total volume per acre in the treated and control plots of each soil group. Because the mean volume growth response within soil groups 2, 4, 7, and 9 were greater than the overall mean, it appears that the benefits of understory vegetation removal would best be achieved by targeting such operations to only those stands with soils characteristic of these groups.

Since the modified CRIFF soil groups did significantly (0.01 level) reduce the variability in overstory volume growth response, it appears that the speculation of varying effects from the consumption of site resources by understory vegetation may be valid.

Figure 3 suggests that at most locations within soil groups 2, 4, 7, and 9, understory vegetation exerted negative interference (i.e. depression) on the overstory pine. This negative interference was most likely in the form of competition for soil water, nutrients, and rooting space. A similar but less severe negative interference or possibly a neutral interference (i.e. no effect) appears to have been produced by the understory vegetation occurring in the majority of locations within soils groups 5 and 6. On the other hand, the effect of understory vegetation growing in soil groups 3 and 8 seems to have been primarily in the form of positive interference (i.e. stimulation).

Table 5. Modified CRIFF soil group definitions and the corresponding original CRIFF soil groups along with Soil Conservation Service subgroups found within each group.

Soil Group Mod.	Soil Group CRIFF	Diagnostic Horizons: Horizon	Diagnostic Horizons: Depth (in)	Drainage Classes	Soil Subgroup
1	H	Histic	surface	VP	All Histosols
2	A	Argillic	< 20	VP,P,SP	Typic Albaquults Arenic Paleaquults Aquic Arenic Paleudults
3	B	Argillic	> 20	VP,P,SP	Typic Paleaquults Grossarenic Paleaquults Grossarenic Paleudults Plithaquic Paleudults
4	F	Argillic	> 20	MW,W,SE	Arenic Paleudults Grossarenic Paleudults
5	B	none		VP,P,SP	Typic Humaquepts Typic Psammaquents Aquic Quartzipsamments
6	G	none		MW,W,SE,E	Typic Quartzipsamments
7	C	Spodic & Argillic	< 20 > 20	VP,P,SP	Ultic Haplaquods Ultic Haplohumods
8	D	Spodic	< 20	VP,P,SP	Typic Haplaquods Aeric Haplaquods
9	D	Spodic	> 20	VP,P,SP,MW	Typic Haplaquods Grossarenic Haplaquods Grossarenic Haplohumods

Table 6. Average initial (1976) measurements and adjusted mean height and per acre volume growth within each soil group during the period 1976-86.

Soil Group	Average Initial Measurement	Adjusted 10-year Growth Control	Adjusted 10-year Growth Treated	Increase Over Control Absolute	Increase Over Control Percent
		- Height (ft) -			
2	25.0	18.1	19.1	1.0	5.5
3	32.0	20.7	22.5	1.8	8.7
4	28.9	20.2	22.1	1.9	9.4
5	28.7	21.8	22.5	0.7	3.2
6	27.5	15.0	16.2	1.2	8.0
7	26.8	22.0	23.4	1.4	6.4
8	30.4	25.3	23.8	-1.5	-5.9
9	27.6	22.0	27.0	5.0	22.7
		- Total Volume (cu.ft/ac) -			
2	719.9	1548.3	1937.8	389.5	25.2
3	1487.5	2352.7	2072.1	-280.6	-11.9
4	914.3	1658.4	2183.4	525.0	31.7
5	1082.6	2128.3	2295.8	167.5	7.9
6	761.6	1155.3	1292.0	136.7	11.8
7	986.7	2061.7	2636.6	574.9	27.9
8	1182.8	2813.9	2312.6	-501.3	-17.8
9	1325.2	2401.6	3383.0	981.4	40.9
		- Merchantable Volume (cu.ft/ac) -			
2	231.2	1238.9	1557.6	318.7	25.7
3	686.6	1907.6	1747.3	-160.3	-8.4
4	312.8	1300.7	1729.4	428.7	33.0
5	526.8	1651.0	1744.0	93.0	5.6
6	233.2	889.5	1031.4	141.9	16.0
7	388.8	1603.0	2044.5	441.5	27.5
8	513.5	2164.7	1871.4	-293.3	-13.5
9	479.9	1781.6	2614.6	833.0	46.8

It is not surprising that soil groups 7 and 9, both Spodosols, had the greatest average volume growth response to understory vegetation removal. Shiver *et al.* (1988) found that after eight years of herbicide treatment in newly planted lower coastal plain slash pine plantations, treated plot height growth was 34.1 percent greater on Spodosols but only 19.8 percent greater on soils lacking a spodic horizon.

The interpretation of the apparent negative volume growth response in soil group 8, however, is unclear. One striking morphologic difference between soil group 8 Spodosols and those in soil groups 7 and 9 involves repeated spodic horizons with depth. Only soils within soil group 8 have this feature which may significantly impact the amount of soil water, nutrients, and rooting space in comparison with soil groups 7 and 9.

Differences in volume growth response between the Ultisols (i.e. soil groups 2, 3, and 4) is slightly more clear. Soils within soil group 2 are generally characterized as having phosphorus deficiencies and rooting space problems. Understory vegetation removal from these sites probably relieved part of this stress by eliminating understory consumption of these two limited site resources. Similarly, the short but severe water deficits exhibited in most soil group 4 Ultisols was most likely reduced when understory consumption of soil water was eliminated. In terms of overstory volume growth, soils within soil group 3, like

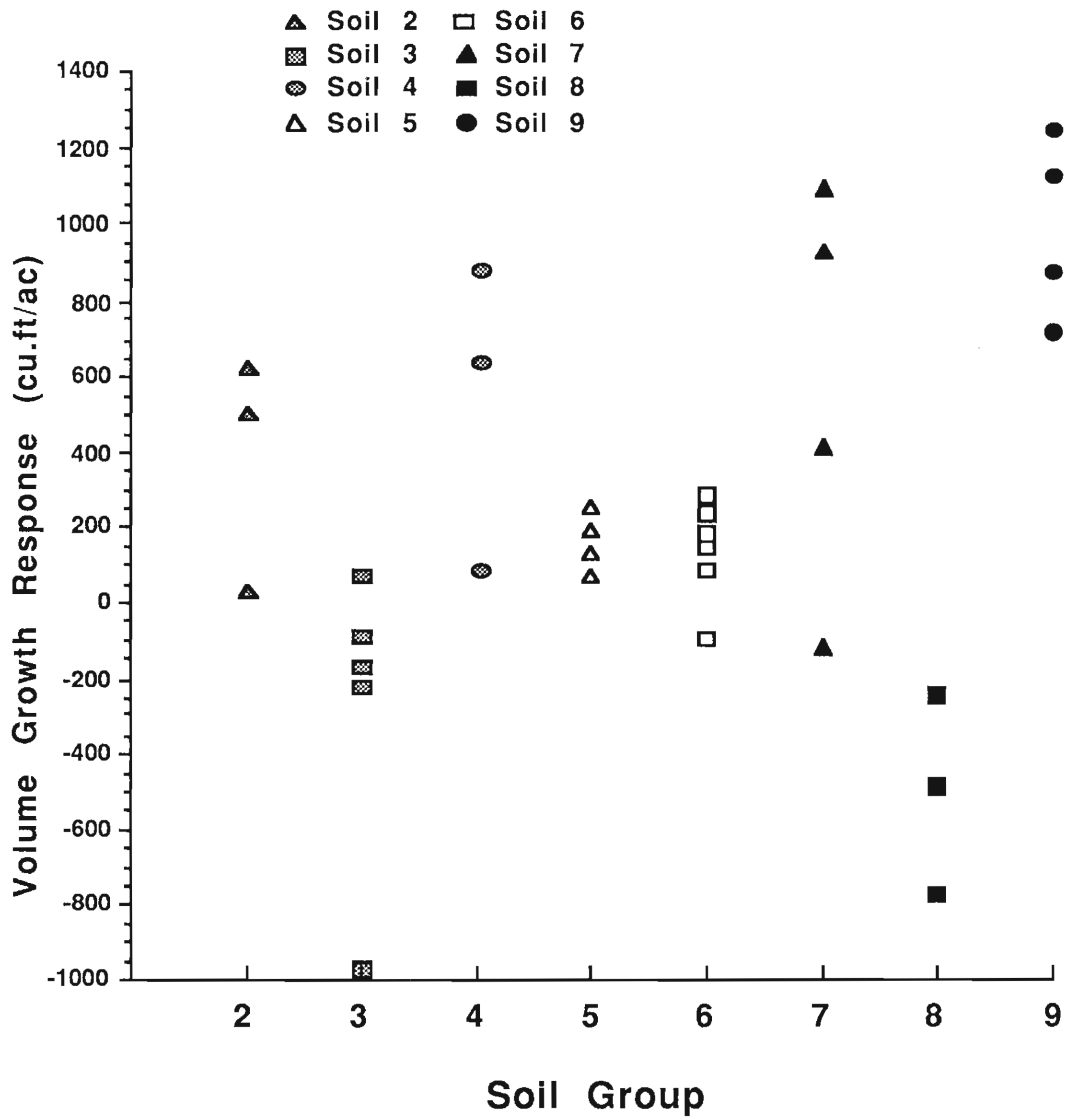

Figure 3. 10-year volume growth response for each soil group.

those of soil group 8, are probably the most productive sites when the understory is left unaltered (Figure 2). The understory vegetation occurring at these sites may be responsible for part of this production capacity, and therefore its removal resulted in decreased volume growth.

Volume growth response in sites within the Entisols soil groups (i.e. groups 5 and 6) was small but fairly uniform. Soils within both these groups generally have low soil water holding capacities and limited available nutrient pools. Therefore, any instantaneous increase in soil water and nutrients which resulted from eliminating understory vegetation consumption was most likely short lived due to this limited storage ability.

GROWTH RESPONSE OVER TIME

The remeasurement data obtained after the second, fourth, sixth, eighth, and tenth growing season following initial understory removal were used to illustrate growth response over time. For each remeasurement year, net total per acre volume growth response values were calculated from the adjusted growth values. The averages of these response values for each soil group are shown in Figure 4.

The average amount of volume growth response within soil groups 4, 7, and 9 steadily increased during the 10 growing seasons. Therefore, early volume growth response within these groups should serve as a good indicator of what the future holds. Conversely, volume growth response within soil groups

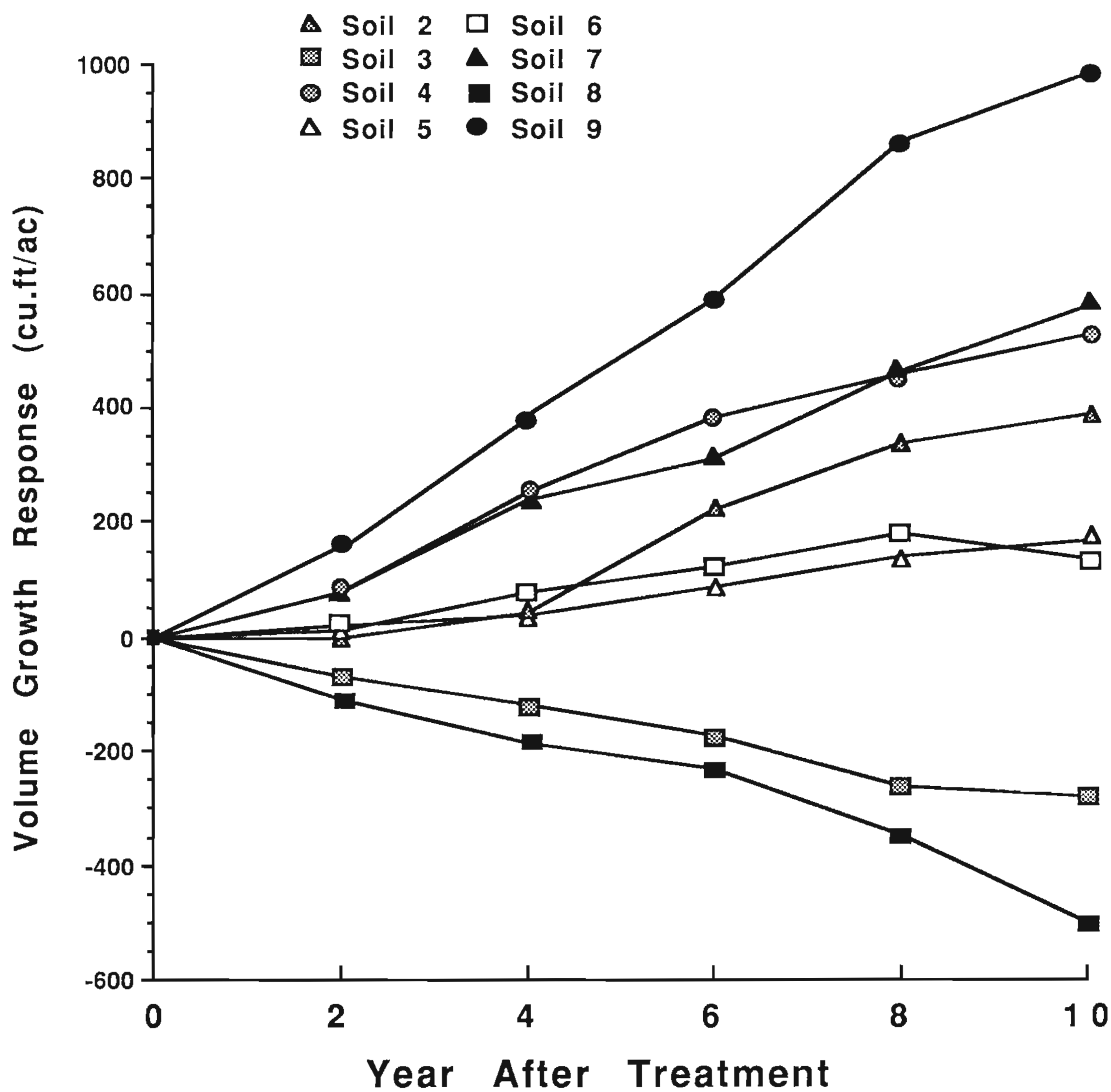

Figure 4. Volume growth response for each soil group for all 2-year measurement periods.

3 and 8 became increasingly negative with time. The trends in merchantable per acre volume growth response over time for each soil group were similar to the total per acre volume trends.

Based on Figure 4, it appears that within the four most attractive soil groups for understory vegetation removal operations (i.e. groups 2, 4, 7, and 9), additional volume growth increases from these operations will continue to accumulate as long as an understory free environment is maintained and intraspecific competition is absent.

SUMMARY

The results from the PMRC understory vegetation study suggest that the presence of this vegetation in 9 to 15-year-old site-prepared slash pine plantations located throughout the Lower Coastal Plain of Georgia and north Florida can significantly reduce overstory growth on certain sites. Ten years after the removal of such vegetation, average net total and merchantable volume growth per acre was 12 percent (236.0 cu.ft) and 14 percent (215.1 cu.ft) greater, respectively, than when the understory was left unaltered. Average individual tree basal area growth increased by 19.1 percent (0.021 sq.ft), and average height growth increased by 7.4 percent (1.5 ft) as a result of this removal.

Although the overall effect of understory vegetation removal was one of increased overstory growth, a great deal of site to site variability existed in the amount of growth increase achieved from the understory removal treatment. Total volume growth increases due to the treatment effect ranged from -984.5 to 1234.2 cubic feet per acre. Seventy percent of this variability was explained when the 32 study locations were separated into modified CRIFF soil groups based on soil morphology.

Understory vegetation exerted the greatest competition effect in two Spodosols soil groups (i.e. groups 7 and 9) and two Ultisols soil groups (i.e. groups 2 and 4). The increase in total volume per acre growth resulting from the elimination of understory vegetation in soil groups 2, 4, 7, and 9 was 25.2 percent (389.5 cu.ft), 31.7 percent (525.0 cu.ft), 27.9 percent (574.9 cu.ft), and 40.9 percent (981.4 cu.ft), respectively. Competition effects from understory vegetation was negligible in the Entisols soil groups (i.e. groups 5 and 6). Within groups 3 and 8, the presence of understory vegetation appears to have had a beneficial effect as indicated by the sharp volume growth decrease observed after understory removal from these sites.

From a forest management perspective, the results of this study suggest that use of soil groups to target understory vegetation control treatments will increase the effectiveness of such operations. If the overall morphology of a given crown closed slash pine plantation's soil matches that of soil group 2, 4, 7, or 9, then understory removal could lead to financial gains by either increasing volume at rotation or allowing for a younger rotation age. However, due to the lack of additional data to test these soil groups, caution is advised in predicting financial gains from these specific groups.

LITERATURE CITED

Bower, D.R., and E.R. Ferguson. 1968. Understory removal improves shortleaf pine growth. J. For. 66:421-422.

Cain, M.D. 1985. Long-term impact of hardwood control treatments in mature pine stands. USDA For. Serv. Res. Pap. SO-214. 8 p.

Clason, T.R. 1984. Hardwood eradication improves productivity of thinned loblolly pine stands. South. J. Appl. For. 8:194-197.

Fisher, R.F., and W.S. Garbett. 1980. Response of semi-mature slash and loblolly pine plantations to fertilization with nitrogen and phosphorus. Soil Sci. Soc. Am. J. 44:850-854.

Grano, C.X. 1970. Small hardwoods reduce growth of pine overstory. USDA For. Serv. Res. Pap. SO-55. 11 p.

Lange, K.D. 1951. Effects of clearcutting understory hardwoods on the growth of a shortleaf-virginia pine stand. J. For. 49:176-178.

McClay, T.A. 1955. Loblolly pine growth as affected by removal of understory hardwoods and shrubs. USDA For. Serv. Res. Note 73, Southeastern For. Exp. Sta. 2 p.

Oppenheimer, M.J., B.D. Shiver, and J.W. Rheney. 1988. Ten year growth response of mid-rotation slash pine plantations to competing vegetation control. Can. J. For. Research (in press).

Pienaar, L.V., W.M. Harrison, T. Burgan, and J.W. Rheney. 1988. Yield prediction for site-prepared slash pine plantations in the coastal plain. PMRC Sch. For. Resources, Univ. of Georgia Technical Report No. 1988-1. 81 p.

Russell, T.E. 1961. Control of understory hardwoods fails to speed growth of pole-size loblolly. USDA For. Serv. South. For. Notes No. 131. pp. 3-4.

Shiver, B.D., M.J. Oppenheimer, and J.W. Rheney. 1988. Eight year results of PMRC coastal plain site preparation study. PMRC Sch. For. Resources, Univ. of Georgia Technical Report No. 1988-7

Soil Survey Staff. 1951. Soil survey manual. USDA Handbook No. 18. U.S. Govt. Printing Office, Washington.