Carter, G.A.; Miller, J.H.; Davis, D.E.; Patterson, R.M. 1984. Effect of vegetative competition on the moisture and nutrient status of loblolly pine. Canadian Journal of Forest Research. 14(1): 1-9.

Effect of vegetative competition on the moisture and nutrient status of loblolly pine

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Received May 18, 1983[2]

Accepted September 1, 1983

CARTER, G. A., J. H. MILLER, D. E. DAVIS, and R. M. PATTERSON. 1984. Effect of vegetative competition on the moisture and nutrient status of loblolly pine. Can. J. For. Res. 14: 1-9.

A field study examined the effects of competing vegetation on the moisture and nutrient status of S-year-old loblolly pines (*Pinus raeda* L.). Similar experiments were conducted on a Piedmont site and a Coastal Plain site using individual pines as experimental units. Predawn measurements of xylem pressure potential were made using detached needle fascicles, and nutrient concentrations in soil and foliage samples were determined monthly. This study was conducted during the 3rd year of a relatively dry 3-year period. On the Piedmont site, elimination of all competing vegetation within 1.5 m of the pines significantly lowered moisture stress when compared with the no-elimination treatment; on the Ccastai Plaince site. differences were significant on only half of rhe assay dates. Removing only arborescent vegetation on the Piedmont site reduced pine water stress one-half as much as removing all vegetation, but on the Coastal Plain site this reduction was about two-thirds of that found following removal of all vegetation. As drought length increased. stress increased, regardless of treatment. Higher levels of competing vegetation significantly reduced available potassium, calcium. magnesium. and manganese concentrations% the loamy sand of the Coastal Plain site. but only potassium was reduced on the Piedmont. None of the treatments significantly affected foliar nutrients at either site.

CARTER. G. A.. J. H. MILLER, D. E. DAVIS et R. M. PATTERSON. 1984. Effect of vegetative competition on the moisture and nutrient status of loblolly pine. Can. J. For. Res. 14: I-9.

Les auteurs ont mesuré les effets de la végétation concurrente sur la teneur en humidité et en éléments de plants de *Pinus taeda* L. âges de 5 ans. Les expériences ont été poursuivies au champ, dans une station des Piémonts et une station de la Plaine Côtière du sud-est des U.S.A. en utilisant des pins individuels comme unités d'expérimentation. Les mesures de tension hydrique dans le xylème avant la levée du jour furent faites sur des fascicules excisés, alors que les concentrations en éléments nutritifs du sol et du fcuillagc furent mesurées mensueliement. L'étude fut conduite durant la Xme année d'une période relativement sèche dc 3 ans. Sur le site des Piémonts, l'élimination de toute végétation concurrentc à 1.5 m des pins a réduit significatlvement le stress hydrique. par comparaison au traitement témoin; sur le site de la Plaine Côtière, les différences n'étaient significatives quc pour la moitit des dates d'essai. L'élimination de la seule végétation arborescentc dans lc site des Piémonts, a réduit de moitié le stress hydrique des pins, comparativement à la réduction consécutive à l'élimination de toute végétation concurrente; cc même traitement a réduit des deux tiers le stress hydrique des pins dans le site de la Plaine Côtière. Le stress hydriquc s'accentuait avcc l'augmentation de la période de sécheresse, indépendamment du traitement. Une forte végétation concurrente a réduit significativement les concentrations en potassium, calcium, magnésium et manganèse échangeables du sable loameux de la Plaine Côtière, mais seulement le potassium fut réduit dans lc cas du site des Piémonts. Aucun des traitcments n'a influencé significativement les concentrations foliaires d'éléments à l'un et l'autrc des sites.

[Traduit par le journal]

Introduction

Loblolly pine (*Pinus taeda* L.) is currently the leading commerical timber species in the southeastern United States. Because of its economic importance. much research has been conducted to determine the effects of controlling competing vegention on its growth. Survival and growth have been correlated with relatively specific levels of arborescent competing vegetation. Grano (1961) found 24-month survival of 1-year-old loblolly seedlings to be significantly correlated with percent of hardwood cover. Ferguson (1958) reported that lst-year survival of planted loblolly seedlings improved with increasing levels of vegetation elimination during dry seasons and that height growth increased roughly in proportion to the degree of elimination.

The effect of nonarborescent vegetation on loblolly pine growth is not extensively documented, however, and researchers have only recently begun to study these effects. In a study involving 7-year-old precommercially thinned loblolly pine, Clason (1978) found that after 5 years of controlling both hardwoods and grasses, pine diameter growth was increased more than when only hardwoods were controlled. Removing only herbaceous vegetation induced no additional growth. Knowe *et* al. (1982). however, found that control of herbaceous weeds in the vicinity of I- to 2-year-old loblolly pines dramatically improved growth, and Nelson *et* al. (198 1) found that height growth response of young loblolly seedlings was significantly related to percent ground cover of weeds and herbaceous biomass.

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[2]Revised manuscript received August 24. 1983.

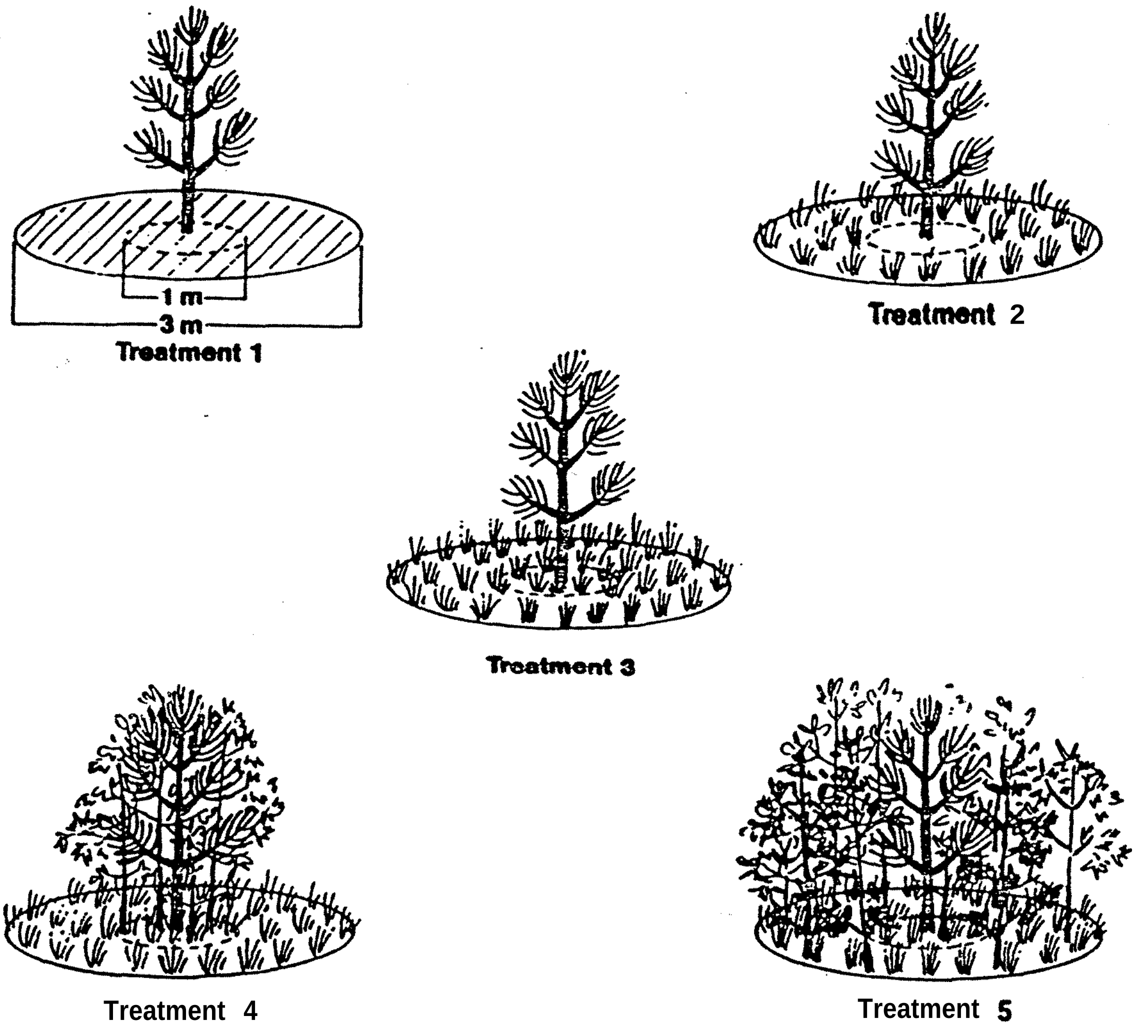

FIG. 1. Levels of competing vegetation by treatment.

Competing vegetation is thought to bring about its effects primarily by decreasing water and mineral nutrient availability, and perhaps also by less well understood allelopathic effects. These alterations in the soil environment are most obviously expressed through reduction in pine growth. The effects of such factors on pine respiration and photosynthesis have been demonstrated (Btix 1962). As a consequence of such findings, at least partial control of competing vegetation is a standard practice in the establishment of commercial pine stands, and current trends are toward increased vegetation elimination. Specific ecophysiological relationships between loblolly pine and arborescent and nonarhorescent competitors are not, however, well defined. This study, which was conducted over the period of June to September 1980, was designed to determine the effect that varying degrees of arborescent and nonarhorescent competition had on the moisture and nutrient status of S-year-old loblolly pines growing in central Alabama.

Study areas

Two study sites with different soil types were chosen. One site was on the Piedmont Plateau near Auburn. in east Alabama. and the other was 24 km to the south on the Upper Coastal Plain. Both sites sup Ported 5-year-old loblolly pine plantations grown from seedlings transplanted from the same nursery.

The Piedmont location. a constant 7% slope. was Site prepared for planting by felling vegetation with a K-G blade and bulldozing the sheared vegetation into windmws. The soil was a Hiwasee sandy loam (Typic Rhodudult) with a sandy foam surface soil varying in depth from about 3 cm on the more elevated end of the slope to 20 cm at the lower end. The subsoil was reddish-brown clay to a depth of 45 cm and dark red clay to a depth of I 10 cm.

The Coastal Plain site. a 9% slope on the average. but located at the base of a hill, was site prepared for planting by injection of hardwoods with 2,4-dichlorophenoxyacetic acid (2.4-D). The soil was a Cowarts loamy sand (Typic Hapludult) with a loamy sand surface soil extending to a depth of about 22 cm over sandy clay loam to a depth of 40 cm and sandy clay to 70 cm.

Met hods

Selection of experimental units

Twenty-five loblolly pines. l.8 to 3 m tail. were selected at each location as experimental units. All trees had significant amounts of both arborescent and nonarborescent vegetation growing near their trunks and were large enough to withstand foliar sampling over the summer. Distances between trees were sufficient to prevent treatment overlap. Trees were assigned to five blocks (five trees each) from the upper region of the slope to the lower.

Treatments

Treatments were randomly assigned within each block. Treatments (Fig. 1) were (1) elimination of all competing vegetation within 1.5 m of the unit tree; (2) elimination of all vegetation within 0.5 m and arborescent vegetation within 1.5 m of the unit tree: (3) elimination of only arborescent vegetation within l .5 m of the tree: (4) elimination of arborescent vegetation from 0.5 to 1.5 m from the unit tree; (5) no vegetation removed.

Treatments were chosen on the basis of their similarities to, though not necessarily equivalent to. the forest management practices of: (i) complete elimination of all vegetative competition within a stand of loblolly pine using herbicides that do not kill pines (presently an experimental procedure); (ii) elimination of hardwoods within a stand and application of a herbicide near the base of each crop tree; (iii) elimination of hardwoods only. with herbicides or hand-clearing; (iv) mowing between rows of trees; (v) no elimination of competing vegetation. No attempt was made to either eliminate or quantify amounts of competing vegetation occurring beyond the 1.5-m radius from each unit tree.

Blocks were treated from June 13 to 17, 1980. Arborescent vegetation was eliminated by shearing to ground level. and nonarborescent competition was controlled by spraying with 1% (v/v) solution of a commercial glyphosate herbicide in water. Unit trees were shielded by plastic wrapping during herbicide applications. Herbicide uptake by pines was prevented by the characteristically strong adsorption of glyphosate to soil particles. Hardwood sprouts were hand controlled over the season and herbicide was reapplied where needed in mid-August.

Field methods

Monitoring of pine water stress

Xylem pressure potential (XPP) was measured with a Scholander-type pressure bomb (Scholander *et al.* 1965) similar to that used by Waring and Cleary (1967). Predawn measurements were made between 0330 and 0530. usually beginning 1 to 4 days after a rainfall and continuing daily until rain fell again. Measurement days were alternated between sites. Needle fascicles from the previous year's growth were cut from the middle to lower one-third of each tree for use in XPP measurements. Only one fascicle per tree was used unless a clearly defined pressure endpoint could not be obtained. Procedure followed was similar to that described by Johnson and Nielson (1969). Occasional spot-check comparisons of XPP values between fascicles collected from the same region of a given pine and between fascicles collected from the middle and lower thirds of the tree indicated a variability within and between these regions of less than ± 0.05 MPa.[3] A rain gauge was installed at each site and checked after each rainfall so that pine water stress could be evaluated with reference to amounts of rainfall and length of dry periods. A total of 1180 usable XPP values were obtained between June 19 and October 4.

XPP was monitored for 17 h on September 27 during a severely dry period at the Piedmont site. Pressure-bomb measurements began before sunrise and were made approximately every 3 h until after sunset. A similar set of measurements was to have been made at the Coastal Plain site on September 28. but an early mowing rainstorm on that date alleviated the previously severe drought conditions.

Soil samples were collected at both locations on or about June 16, July 5, August 1, August 30. and October 6 to determine soil nutrient changes with respect to treatment. Removing soil from the root zone of a 5-year-old pine on each site with pressurized water indicated that essentially all roots except the tap root were located in the upper 20 cm of soil. Soils were sampled to a 20-cm depth with a tube sampler approximately 0.75 m from the base of each tree (in the outer competition-control zone). Cores were randomly taken from four points on the circle. composited, and mixed well. Subsamples were collected in metal cans immediately after mixing, oven-dried at 105°C. and percent soil moisture was determined as grams H_2O per gram dry weight of soil. The remaining sample was air dried. passed through a 2.0-mm mesh sieve, and stored at 3°C prior to nutrient analyses.

Foliage was sampled monthly from June 12 to October 3. Two fascicles from the previous-year's growth were collected from each of four branch locations having approximately 90" spacing, and two fascicles were taken from the main trunk. All needles were collected from the middle one-third of the crown because it has been reported that N. P. K. Ca. and Mg levels in this region represent an approximate average of the amounts present throughout the tree (Wells and Metz 1963). The 10-fascicle samples were wrapped in plastic in the field and taken to the laboratory where they were stored frozen until analyzed for nutrient concentrations.

The density and total basal area of each species of arborescent competitor was determined for each plot of treatments 4 and 5 on September 4. At the end of the growing season all vegetation within 1.5 m of each tree was harvested. Only that portion of vines actually within 1.5 m of each tree was included in the harvest. Clipped vegetation was bagged in plastic and taken to the laboratory where fresh weights were obtained. Samples were ovendried at 75°C to constant weight.

Pine trunk groundline diameters were measured at the time of treatment application and again on September 4.

Analytical methods

A Perkin-Elmer model 373 atomic absorption spectrophotometer with an air-acetylene flame was used for both soil id foliar cation analyses. Soil nutrients were extracted from duplicate 5-g samples of air-dried soil with 20 mL of a 0.05 N HCl and 0.025 N H_2SO_4 solution (Mehlich 1953). Extracts were filtered through Whatman No. 1 paper and the concentrations of K. Mn. Cu. and Zn were determined in the clear. undiluted extracts. Ca and Mg were determined from 1.5-mL samples of the extract diluted with 6.0 mL of a 0.5% lanthanum (as La_2O_3) solution.

Soil phosphorus was determined by diluting 1.5 mL of extract with 6.0 mL of phosphorus reagent C (Watanabe and Olsen 1965). Thirty minutes were allowed for development of the blue color and concentration was then read on a Beckman model 35 spectrophotometer at a wavelength of 882 nm. Soil pH was determined in 1 : 1 (v:v) soil and distilled water mixtures with a glass electrode. Soil particle size and organic matter analyses were petformed using a hydrometer method modified from Black (1965) and methods outlined by Jackson (1958), respectively.

Previously-frozen foliage samples were oven-dried at 70°C, ground in a Wiley mill to pass a 40-mesh screen. and 0.5-g subsamples were dry-ashed at 450°C for at least 6 h. To each ashed sample 20 mL of 0.40 N HCl with 0.2% lanthanum was added. The mixture was allowed to sit for 2 h and was then filtered through Whatman No. 2 paper. Concentrations of K, Ca. Mg. Mn, Cu. and Zn were determined in the clear undiluted extracts by atomic absorption spectrophotometry.

Foliar phosphorus was determined by the vanadomolybdate method of Jackson (1958). One millilitre of extract was diluted with 9.0 mL of vanadomolybdate diluted reagent. Thirty minutes were allowed for development of the yellow color. then absorption was read at a wavelength of 425 nm with a specttophotometer. Owing to small amounts of material available, duplicate foliar nutrient analyses were not attempted.

Total N was determined on soil and foliage samples by digesting 0.5 g of air-dried soil or 0.1 g of ground foliage in a Kjeldahl digestion mixture using an aluminum block at 330°C. Duplicate soil samples were analysed, but there was insufficient material for analysis of duplicate foliage samples. NH_4 concentration was determined using an ammonia electrode with an Orion(R) 901 microprocessor ion-analyzer. The literature reports close agreement of nitrogen values obtained by the ammonia elatrode with those obtained by distillation and titration (Bremmer and Tabatabai 1972; Eastin 1976).

In determining potentially available soil water, undisturbed cores (5.4 cm diameter × 6 cm deep) were extracted from the vicinity of two unit trees at each study site. Soils in the uppermost and lowermost blocks wen sampled at 50 cm from the trunks. Duplicate sets of cores comprising the depth segments 0–6, 6–12. 12–18, and 18–24 cm were collected. Water retention capacities were determined on these cores at 0.033 and 1.5 MPa of pressure using a tension-plate method. Percent available water was calculated on a volume basis (cubic centimetres per cubic centimetres).

[3] 1 MPa = 10 bars.

TABLE 1. Most important vegetative competitors in no-elimination plots (treatment 5) on each site[a,b,c]

	Arborescent basal area (cm^2/m^2)	Nonarborescent biomass (g/m^2)
	Piedmont	
Rhus glabra L.	356	
Carya spp.	177	
Liquidambar styraciflua L.	119	
Pinus taeda	109	
Lonicera japonica Thunb.		186
Rubus spp.		35
Uniola spp.		28
Smilax rotundifolia L.		12
	Coastal Plain	
Liquidambar styraciflua L.	7133	
Quercus hemisphaerica Bartr.	456	
Pinus taeda	366	
Quercus nigra L.	263	
Vaccinium spp.	189	
Pinus elliottii Engelm.	165	
Gelsemium sempervirens (L.) St. Hil.		56
Andropogon virginicus L.		38
Panicum spp.		15

[a]Frequency of all species was 100%.
[b]Values are the mean of five plots on each site.
[c]Only species with mean basal area greater than 100 cm^2/m^2 or mean biomass greater than 10 g/m^2 are listed.

Results and discussion

Competing vegetation

The most important competing arborescent and nonarborescent species on basal area and biomass bases, respectively, are listed for each site in Table 1. Vines were the most important nonarborescent competitors at each site. Grasses were relatively more important as competitors on the Coastal Plain than on the Piedmont.

Pine moisture stress

Complete elimination of competing vegetation within I .5 m of the pine (treatment 1) consistently induced lower predawn moisture stress levels (higher XPP's) than the no-elimination treatment (treatment 5) over the entire experimental period (Table 2, Fig. 2). This is attributable to decreased transpirational water loss from the soil. XPP differences: would be expected to be greater if entire stands were treated rather than individual plots, due to the absence of possible edge effects caused by vegetation outside our 3 m diameter treatment plots.

Highest predawn moisture stress levels on the Piedmont site were - 1.08 and - 1.06 MPa for treatments 3 and 5. respectively on September 27 (Table 2). Highest stresses on the Coastal Plain were -0.90 and -0.92 MPa for treatments 4 and 5 on August 28. At both sites, stress levels were highest during the longer dry periods (Fig. 2). Daily XPP values differed at each site due to differences in occurrence and amounts of rainfall received at' the locations. During the experimental period, rainfall at the Piedmont site occurred on 19 days and totalled 31 cm and at the Coastal Plain site occurred on 17 days and totalled 26 cm. Rain was rarely received at both sites on identical dates.

During the longest dry period at the Piedmont site (August 18 to 30), the mean moisture stress regime for treatments remained constant with treatment 5 >3 >4 >2 > 1. On the day with the highest observed stress levels (August 30), both treatments 1 and 2 induced pine moisture stress levels significantly lower than those for treatment 5. Moisture stress levels induced by treatments 1 and 2 were also significantly lower than those of treatment 3. Thus, elimination of herbaceous vegetation yieided a greater reduction in moisture stress than elimination of only arborescent vegetation on this date.

Leaving arborescent vegetation within 0.5 m of the tree (treatment 4 vs. treatment 3) did not significantly increase water stress except on August 5 on the Coastal Plain ($p = 0.05$). However, stress values for treatment 4 on all other dates were numerically higher on the Coastal Plain. Removing nonarborescent vegetation within 0.5 m of the tree (treatment 2

TABLE 2. Treatment means of predawn xylem pressure potential (megapascals) grouped by dry periods

	Treatment*				
Date†	1	2	3	4	5
			Piedmont		
7/29	0.27*b*	0.33*ab*	0.30*b*	0.32*ab*	0.39*a*
8/2	0.37*c*	0.59*ab*	0.45*bc*	0.61*ab*	0.710
8/4	0.49*c*	0.71*ab*	0.54*bc*	0.71*ab*	0.86*a*
8/15	0.296	0.32*ab*	0.38*ab*	0.34*ab*	0.40*a*
8/21	0.36*c*	0.36*c*	0.52*ab*	0.45*bc*	0.59*a*
8/23	0.44*c*	0.52*c*	0.70*ab*	0.58*bc*	0.81*a*
8/26	0.52*c*	0.59*bc*	0.74*ab*	0.74*ab*	0.87*a*
8/30	0.63*c*	0.66*bc*	0.88*a*	0.85*ab*	1.00*a*
9/27	0.81*b*	1.08*a*	0.90*ab*	0.97*ab*	1.06*a*
			Coastal Plain		
8/3	0.51*c*	0.54*bc*	0.65*ab*	0.74*ab*	0.77*a*
8/5	0.54*ab*	0.55*ab*	0.516	0.73*a*	0.75*a*
8/7	0.57*a*	0.63*a*	0.65*a*	0.81*a*	0.80*a*
8/18	0.536	0.56*ab*	0.59*ab*	0.71*a*	0.70*a*
8/22	0.60*c*	0.71*abc*	0.66*bc*	0.81*ab*	0.87*a*
8/24	0.62*b*	0.70*ab*	0.67*ab*	0.87*a*	0.79*ab*
8/28	0.68*a*	0.81*a*	0.77*a*	0.90*a*	0.92*a*
9/17	0.65*b*	0.71*ab*	0.76*ab*	0.83*ab*	0.90*a*

*Means within rows having a common letter are not significantly different ($p = 0.05$) as determined by Duncan's multiple range test.
†Month/day.

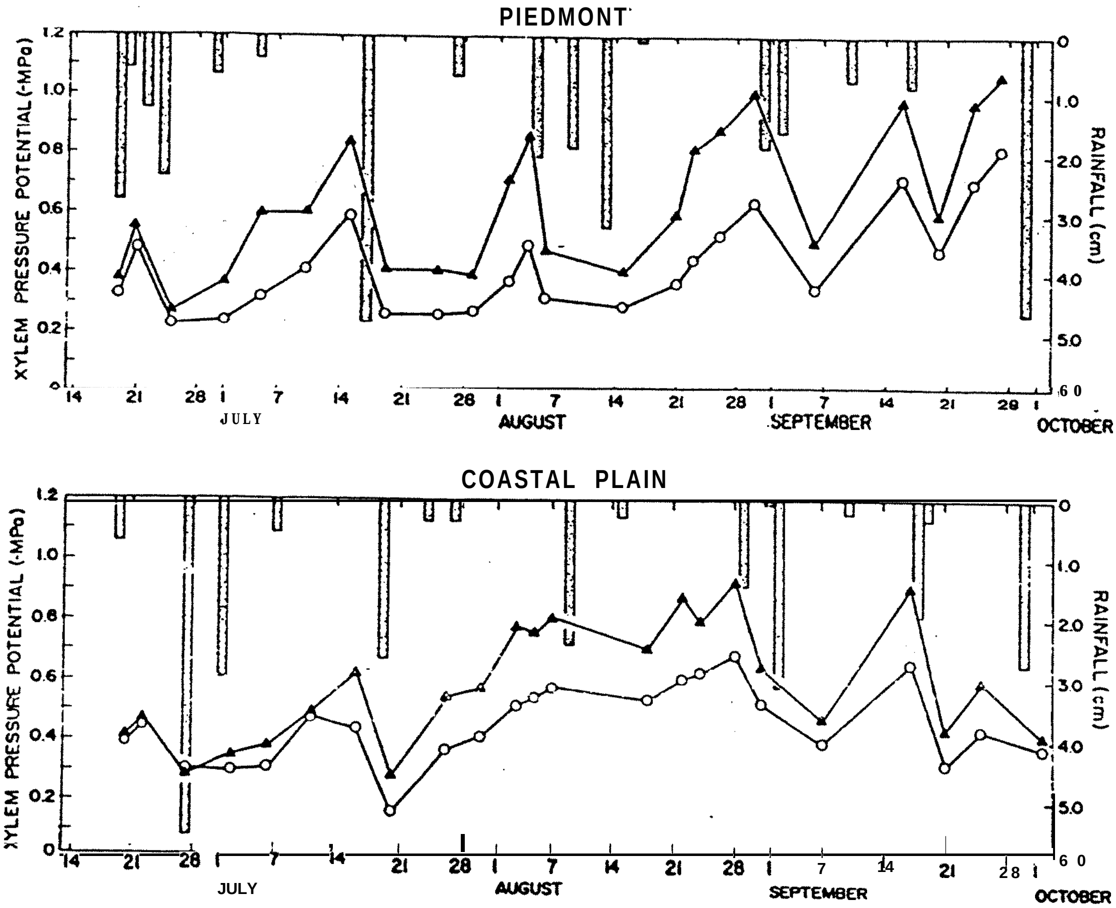

FIG. 2. Xylem pressure potentials of loblolly pine trees with no vegetation elimination (▲) and complete elimination (●).

vs. treatment 3) significantly reduced moisture stress at the Piedmont site on August 21.23. and 30. Removing arborescent vegetation from 0.5 to 1.5 m from the tree (treatment 4 vs. treatment 5) significantly lowered water stress only on August 21 and 23 and only on the Piedmont; however. values on all other dates were numerically somewhat lower. Removing all arborescent vegetation and nonarborescent vegetation within 0.5 m of the tree (treatment 2 vs. treatment 5) significantly reduced moisture stress on four dates at the Piedmont site and on one date at the Coastal Plain site. Removing only arborescent vegetation (treatment 3 vs. treatment 5) significantly reduced moisture stress on three sampling dates on the Piedmont and twice on the Coastal Plain.

Effects on the Coastal Plain were often similar to those on the Piedmont. Linear correlation coefficients (r) between predawn XPP during the longest dry period and several parameters for quantifying degree of competition are presented in Table 3. At the Piedmont site. each parameter was significantly correlated ($p < 0.05$) with XPP. The most highly correlated parameter was dry weight of total competing vegetation (r = 0.70) followed by both dry weight of nonarborescent (r = 0.67) and fresh weight of nonarborescent vegetation (r = 0.67). Only dry weight of total vegetation was significantly correlated with predawn XPP at the Coastal Plain site. Most of the observed differences between sites were thus attributable to the fact that on the Coastal Plain 90% (fresh weight) of the total vegetation was arborescent. whereas on the Piedmont only 59% was arborescent (Table 4). Illustrative of this difference is the fact that removing nonarborescent vegetation within 0.5 m of the tree (treatment 2 vs. treatment 3)

TABLE 3. Linear correlations (r) between parameters quantifying competing vegetation and predawn xylem pressure potential during the longest dry period at each site

Competition parameter	Piedmont		Coastal Plain	
	r	p*	r	p
Density. arborescent	0.48	0.0153	0.39	0.054
Basal area, arborescent	0.49	0.0119	0.32	0.122
Fresh weight, arborescent	0.54	0.0048	0.39	0.053
Dry weight. arborescent	0.52	0.0080	0.21	0.309
Fresh weight. nonarborescent	0.67	0.0002	0.23	0.275
Dry weight, nonarborescent	0.67	0.0002	0.24	0.253
Fresh weight, total	0.58	0.0026	0.36	0.077
Dry weight. total	0.70	0.0001	0.52	0.007

*The probability of a larger absolute value of r if the actual correlation is zero.

significantly reduced moisture stress on August 21, 23, and 30 at the Piedmont site where 41% of the competing vegetation was nonarborescent but did not significantly affect stress on the Coastal Plain where only 10% was nonarborescent.

At the end of the dry period of September 20 to 27 at the Piedmont site, the drought was so severe that only removal of all vegetation (treatment I) resulted in significantly lower stress levels (Table 2).

Pines subjected to the higher moisture stress levels of treatments 3, 4, and 5 would be expected to exhibit reduced growth owing to decreased cell turgor. more so than pines subjected to treatments 1 and 2. It is possible that small but statistically significant differences in high or low stress levels have a neg-

TABLE 4. Mean fresh weights (grams per square metre) of competing vegetation associated with each treatment on each site'

Site	Treatment 1	2	3	4	5
			Arborescent vegetation		
Piedmont	0	0	0	138	745
coastal Plain	0	0	0	153	1509
			Nonarborescent vegetation		
Piedmont	0	193	292	358	512
Coastal Plain	0	84	134	148	174
			Total vegetation		
Piedmont	0	193	292 •	4%	1257
Coastal Plain	0	84	134	301	1683

*There were no significant differences (p = 0.05) in vegetation fresh weights between blocks.

ligibie biological effect. However, the study by Brix (1962) indicated that in lobloliy pine seedlings, respiration rate dramatically declined from the normal when needle diffusion pressure deficit (DPD) increased to 8 atm. DPD and XPP are indicators of the same plant parameter. viz., water potential (0.1 MPa = 0.987 atm). Therefore, if the findings of Btix (1962) are applicable here, it is possible that pines subjected to treatments 1 and 2 at the Piedmont site were able to maintain predawn respiration rates that were approximately equal to those expected to occur in well-watered iobioily pines. Treatments 3, 4, and 5 would be expected to maintain predawn respiration rates as low as 60 to 70% of those in pines subjected to treatments 1 of 2, perhaps resulting in decreased growth rates.

On August 28, the day which produced the highest recorded stress levels of the experimental period on the Coastal Plain, there were no significant differences between treatment means (p = 0.05). Neither were there significant treatment differences on August 7, the last measurement day of the second-longest dry period (July 30 to August 7). In fact. within each of these two dry periods, moisture stress induced by elimination of ail vegetation within 1.5 m of the pine (treatment 1) was significantly less than that found under no-elimination conditions (treatment 5) only on the first two of four measurement days, as well as periodically throughout the experimental period.

Mean stress levels associated with the no-elimination conditions (treatment 5) generally were greater at the Piedmont site than at the Coastal Plain site. All pines on the more loamy soils of the Coastal Plain site were subjected to less drought stress than those on the more clayey soils of the Piedmont. These findings were not expected since drought periods were similar in length at both sites, but total rainfall was less and occurred less frequently at the Coastal Plain site. it is therefore apparent that differences in edaphic conditions between sites significantly influenced stress levels.

Percent available water was determined on undisturbed cores to determine soil-moisture reserve capacities. On a volume basis, available water-holding capacity at the Coastal Plain site was 2.96%. compared with 1.68% at the Piedmont site. Thus, the Piedmont site had 43% less water-holding capacity. Periodic sampling of the upper 20 cm over most of the summer indicated the Piedmont soil had less moisture than the calcuiated wilting point, while the Coastal Plain soil had moisture levels above the wilting point. Aiso, Coastal Plain pines may have had access to subsurface drainage water originating further uphill. Such flow would be facilitated by soil profile characteristics (i.e., loamy sand overlying sandy clay) at the site. Competing vegetation more quickly depleted available soil moisture on the Piedmont site and induced greater moisture stress in all treatments compared with the Coastal Plain site.

The most striking difference between the sites in response to a given treatment occurred with removal of only arborescent vegetation (treatment 3). On the Coastal Plain, treatment 3 induced stress levels that were significantly lower than those of treatment 5 (no vegetation elimination) on three dates, but they were never significantly higher than total competition control (treatment 1). However, on the Piedmont, treatment 3 induced stress levels similar to those of treatment 5 except on July 5.

There would appear to be two major factors contributing to the differences between sites in response to treatment 3. First, edaphic conditions at the Coastal Plain site would moderate competition-induced moisture stress. Secondly, the mean nonarbotescent biomass (also total biomass for treatment 3) on the Piedmont was more than twice that on the Coastal Plain (Table 4), thus depleting soil moisture to a greater degree. A combination of these two factors is likely.

Explaining the relatively high stress levels associated with treatment 3 at the Piedmont site on a biomass basis is difficult. Mean freshweight biomass of nonarborescent competing vegetation associated with treatments 4 (358 g/m^2) and 5 (512 g/m*) was greater than for treatment 3 (292 g/m^2), although stress levels were seldom significantly different between treatments (Tables 2 and 4). Explanation becomes more difficult when mean total fresh biomass for these treatments are compared (292 g/m^2 for treatment 3,496 g/m^2 for treatment 4, and 1257 g/m^2 for treatment 5, Table 4). Although these differences in biomass of competing vegetation arc marked, sizable portions of total biomass associated with treatments 4 and 5 were weights of limbs and trunks that transpire relatively little. Therefore, nonarborescent vegetation would be expected to transpire more than arborescent vegetation per unit fresh weight. Also, the foliage of the arborescent vegetation associated with treatments 4 and 5 possibly reduced transpiration rates in understory nonarborescent vegetation through shading, particularly in the case of treatment 5, and thereby partially reduced soil water depletion by nonarborescent vegetation. In contrast, essentially ail of the total competing biomass associated with treatment 3 would be transpiring more &cause it was exposed to full sunlight with only minimal shading from the unit pine and trees outside the plot. The fact that nonarborescent vegetation was more highly correlated with predawn XPP than arborescent vegetation on the Piedmont (Table 3) emphasizes the importance of nonarborescent species in the competition for soil moisture at this location. The low degree of correlation of XPP with all parameters but total dry biomass at the Coastal Plain site supports prior suppestions that edaphic factors had a confounding influence on XPP responses to treatment. The very low correlation coefficients for both fresh and dry weights of nonarbotescent vegetation (r = 0.23 and 0.24, respectively) appear to support the suggestion that levels of nonarborescent vegetation at the Coastal Plain site were not sufficiently high to appreciably deplete soil moisture and thereby induce moisture stress in the pines. The fact that density and fresh weight of arborescent vegetation were nearly significantly correlated (p = 0.05) with predawn XPP suggests that arborescent vegetation was more influential than non-

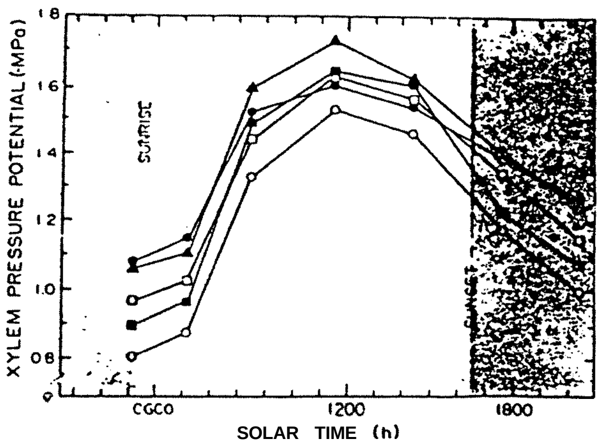

FIG. 3. Diurnal changes in loblolly pine xylem pressure potentials during a dry period on the Piedmont; O, treatment 1; ■, treatment 2; ●, treatment 3; □, treatment 4; ▲, treatment 5.

arborescent vegetation upon pine moisture at the *Coastal* Plain site.

Treatment means of XPP measured at the Piedmont site during a 17-h period on September 27 are presented in Fig. 3. September 27 was the last measurement day of the drought which induced the highest moisture stress of the experimental period at the site. Minimum air temperature recorded during the day was 13°C at 0440 and the maximum recorded was 35°C at 1330. Sunrise occurred at 0536 and sunset was at 1735. The sky was free of haze and cloudless until approximately 1500 when cirrostratus clouds began to move over the area. By 1600, these clouds covered approximately 80% of the visible sky. Cloud cover was 100% by 1800.

During daylight hours, treatment means within each time period were not often significantly different ($p = 0.05$) from each other, whereas the change in stress levels combined for all treatments over time was highly significant ($p = 0.01$) between any two times of measurement (Pig. 3). The lowest mean needle XPP recorded during the day was −1.73 MPa for treatment 5 at noon, and treatment 5 usually induced the most negative XPP throughout the day. The only treatment which induced stress levels significantly lower than those associated with no-elimination conditions (treatment 5) during the 17-h period was elimination of all vegetation within 1.5 m of the pine (treatment 1). Treatment 1 induced moisture stress levels which were on the average 0.1 to 0.3 MPa less stressful than those associated with other treatments throughout the day. However. the results of Brix (1962) indicate that net photosynthesis in loblolly pine seedlings begins to decrease dramatically at a leaf DPD of 0.4 MPa and stops completely at 1.1 MPa. Therefore, assuming the results of Brix (1962) are applicable here, even though treatment 1 provided some lessening of daytime stress levels, all pines had XPP values suggesting a reduction of net photosynthetic rates to zero by 0900.

In addition, Brix (1962) found that as seedling needle DPD increased from approximately 1.4 to 3.1 MPa, respiration rate increased greatly. Therefore, during the highest stress periods of the day, respiration rates probably increased, thereby increasing the rate of depletion of stored carbohydrates. Such a depletion would be particularly important in those pines which were unable to carry on net photosynthesis during any period in the day.

Soil nutrients

Treatment means of combined June through October data for soil nutrients. adjusted for initial concentrations, are found in Table 5. Comparing adjusted means at the Piedmont site indicates that soil K concentrations in treatments 1 and 2 were significantly ($p = 0.05$) higher than those of treatments 4 and 5. On the Coastal Plain, soils of treatments I, 2, 3, and 4 had higher adjusted K. Ca, and Mg concentrations than those of treatment 5. Also, Mn levels associated with treatment 1 were higher than those of treatments 2, 3, and 5 at the Coastal Plain site.

Differences in adjusted cation concentrations may be due to both inputs 'into the soil from decomposing herbicide-killed vegetation in the plots of treatment 1 and higher rates of uptake in plots having greater amounts of competing vegetation. The latter is probably the more likely explanation because the plots of treatment 3 had higher concentrations of the above cations even though herbicide treatment was limited to within 0.5 m of the pine, and soils were sampled 0.75 m from the pine.

There were no significant changes in soil pH over the period owing to treatment or seasonal fluctuations. Soil pH averaged 4.7 ± 0.2 and 5.7 ± 0.2 on both the first and last sampling dates at the Coastal Plain site and Piedmont sites, respectively.

Foliar nutrients

Adjusted treatment means of foliar nutrients are presented in Table 6. Significant changes ($p = 0.05$) in foliar nutrient concentrations did not occur in a consistent pattern corresponding to degree of competition. On an overall basis, P levels associated with treatment 1 at the Piedmont site were significantly lower than those of the other treatments, and Mn concentrations were significantly lower for treatment I than for treatment 5.

These results suggest that increased competition for available soil nutrients by the highest levels of competing vegetation did not significantly decrease foliar nutrient contents in the 1-year-old needles.

Diameter growth

Pine groundline diameters measured at the time of treatment application averaged 4.0 ± 1.9 cm at the Piedmont site and 3.3 ± 0.9 cm at the Coastal Plain site and averaged 4.7 ± 1.1 cm and 3.6 ± 0.8 cm at the respective sites on September 4. Analysis of covariance and subsequent r-test comparisons of least-squares treatment means indicate there were no significant differences in diameter growth rates induced by a given treatment at either site during the relatively short interval between measurements.

Conclusions

Moisture stress responses to treatment at the Piedmont site indicate than nonarborescent vegetation, when present in large amounts, can be at least as effective as arborescent vegetation in inducing moisture stress in 5-year-old loblolly pines. Control of nonarborescent vegetation within 0.5 m of the pine, in addition to removal of arborescent competition within 1.5 m, induced moisture stress which was usually significantly lower than in pines surrounded by undisturbed competing vegetation. Removal of only arborescent vegetation within 1.5 m of the pines, or removal of only arborescent vegetation from 0.5 to 1.5 m, often did not significantly reduce moisture stress below that of pines with undisturbed competing vegetation. The relatively high abundance of nonarborescent vegetation at the Piedmont site appears to be the major factor responsible

TABLE 5. Soil nutrient means (parts per million) adjusted for initial concentrations

	Nutrient element*							
Treatment	N	P	K	ca	Mg	Mn	Cu	Zn
				Piedmont				
1	1644a	3.7a	85a	2126	51a	101a	0.70	0.8a
2	1709a	4.6a	87a	2146	50a	113a	0.8a	I .0a
3	1766a	3.5a	77ab	260a	54a	109a	0.80	I.0a
4	1651a	8.1a	70bc	2156	48a	102a	0.70	1.0a
5	1672a	4.4a	65c	230ab	51a	113a	0.7a	0.9a
				Coastal Plain				
I	417a	11.3a	22a	54a	8a	12a	0.3a	0.6a
2	424a	11.3a	18b	52a	7a	10b	0.3a	0.6a
3	3790	11.3a	18b	52a	8a	10b	0.3a	0.5a
4	379a	10.1a	20a	58a	8a	12a	0.30	0.6a
5	433a	15.9a	16c	436	5b	9b	0.3a	0.5a

*Means from a site with a common letter in the same column are not significantly different ($p = 0.05$) as determined by Duncan's multiple range test.

TABLE 6. Foliar nutrient means adjusted for initial concentrations

	Nutrient element*							
	% of dry weight					ppm		
Treatment	N	P	K	ca	Mg	Mn	Cu	Zn
				Piedmont				
I	0.85a	0.083b	0.4-a	0.375a	0.081a	1566	2.4a	32.90
2	0.85a	0.091a	0.394b	0.368a	0.081a	182a	4.5a	34.6a
3	0.86a	0.092a	0.446a	0.360a	0.088a	1606	2.4a	33.6a
4	0.840	0.091a	0.427a	0.383a	0.087a	176ab	2.6a	34.0a
5	0.83a	0.096a	0.449a	0.3720	0.088a	181a	2.7a	34.2a
				Coastal Plain				
1	0.67ab	0.098a	0.3486	0.426a	0.089a	2646	1.5a	44.36
2	0.71a	0.1020	0.394a	0.412a	0.097a	268b	3.5a	51.10
3	0.730	0.092a	0.3476	0.428a	0.094a	295a	2.1a	49.6a
4	0.68ab	0.098a	0.3366	0.428a	0.087a	244b	2.20	44.36
5	0.64b	0.090a	0.3366	0.415a	0.08447	2456	2.4a	42.0b

*Means from a site with a common letter in the same column are not significantly different ($p = 0.05$) as determined by Duncan's multiple range test.

for the relatively small benefit of removing only arborescent vegetation.

Responses to vegetation elimination treatments varied between sites even though total competing biomasses were similar. This emphasizes the importance of edaphic factors in influencing competition-induced stress. On the Coastal Plain site, the nonarborescent vegetation present in relatively low amounts rarely induced significantly higher moisture stress than that associated with elimination of all vegetation within 1.5 m of the pine. It is not surprising, therefore, that herbicide control of nonarborescent vegetation within 0.5 m of the pine following removal of arborescent vegetation from within 1.5 m seldom afforded significant additional reduction in pine moisture stress.

Results from 'a monitoring of diurnal changes in moisture stress suggest that during severe droughts the primary advantage of decreasing moisture stress by decreasing competition occurs during nighttime growth periods. since stress values were not statistically different between treatments during most of the daylight hours. Additional information concerning the effects of moisture stress on loblolly pine physiology needs to be obtained before the biological significance of small diurnal reductions in stress can be established.

Results also indicate that greater degrees of vegetative competition reduced available soil K, Ca, Mg, and Mn concentrations but did not significantly decrease foliar total N. P. K, Ca, Mg, Mn, Cu, or Zn concentrations. at least not within 4 months after initiation of control measures. Thus. reduction of competing vegetation during one growing season-influenced pine moisture status more than foliar nutrition.

Test treatments only simulated actual operational and potential treatments of use in pine management. The various degrees of control were limited to within 1.5 m of each pine and no attempt was made to control roots originating from outside this radius. Even with these limitations, plots of this size were found to be well suited for the present study. Examinations of root distribution described earlier suggested that most root mass of the pines was contained within the 1.5 m radius. However, 1.5-m radius plots should be considered a minimal size for competition studies on similarly aged pine. Sampling pines spaced 3 m apart within 15 x 15 m or larger treated stands would be desirable for future studies. Possible edge effects could then be ignored in areas with similar levels of competing vegetation.

Given the above, results suggest that actual amounts of non-arbotescent vegetation on a given site should be estimated. and if found to occur in amounts similar to or less than those at the Coastal Plain site, it probably would not be cost effective to use significant amounts of labor. material, and equipment toward its elimination from the vicinities of similarly aged pines. In such situations, removal of arbotescent vegetation and subsequent control of resprouts is probably the only worthwhile control measure. in situations involving higher amounts of nonarborescent vegetation, control of both arbotescent and nonarborescent vegetation would be desirable.

Acknowledgements

The authors thank Michael W. Folsom for his valuable field assistance, Dr. Nguyen Hue for advice on nutrient analyses, and Richard Morgan, Erwin Chambliss, and Louis Felton for their assistance in the lab.

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