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Abstract. Growth of slash pine planted on a well-prepared Florida sandhill site and treated with NP fertilizer, irrigation, and weed control (applied singly and in factorial combination) was improved in almost direct proportion to the number of treatments applied. Five years after planting, untreated trees averaged 1.7 m tall, 1.52 cm dbh, and 821 cm^3 in stemwood volume. In contrast, trees subjected to any single treatment, two combined treatments, or three combined treatments were about 45, 70, and 110 percent taller; 100, 150, and 230 percent larger in dbh; and contained 90, 170, and 330 percent more stemwood volume. Both available soil moisture and nutrients limited tree growth on these sites during various times of the year. Soil moisture deficiencies during the previous fall and current spring restricted elongation of the first flush of growth, while nutrient deficiencies limited elongation of subsequent or late flushes as well as diameter growth. Factorial combinations of treatments generally resulted in lower concentrations of N and K in current annual foliage, while fertilization caused slightly higher concentrations of foliar P. Both weed control and irrigation increased available soil moisture and thus decreased the number of days during the growing season that trees were growing under moisture stress. ***Forest Sci. 19:197–202.***

Additional key words. *Pinus elliottii*, forest fertilization, irrigation, weed control.

GREENHOUSE TESTS have consistently indicated that slash pine (*Pinus elliottii* Engelm.) seedlings growing on the deep, sandy, west Florida soils will respond to N and P fertilizers. However, field trials have failed to confirm greenhouse findings (Brendemuehl 1968). In greenhouse studies, available soil moisture, competition from other plants, insect and disease damage, and nutrient availability are held constant. Thus, test seedlings receive maximum benefit from the applied fertilizer. In the field, however, fertilizer effects are often reduced or confounded because these same factors are uncontrolled.

The purpose of this investigation was to determine the relative importance of nutrients, soil moisture, and competing vegetation on growth of slash pine planted on a Florida sandhill soil.

Methods

The study was installed on a typical sandhill site in Calhoun County, Florida, in 1966. Soil of the study area is Lakeland sand, which is a member of the siliceous, thermic family of Typic Quartzipsamments. These excessively drained sands are inherently droughty and low in available nutrients, especially N and P. For example, these soils are able to hold only 1.3 cm of available water per 0.3 m of soil, contain 0.3 ppm extractable P (ammonium acetate at pH 4.8), and contain less than 1 percent organic matter in the surface 0.3 m of soil.

In preparation for planting, the area was chopped with a duplex brush cutter in the fall of 1962 and of 1964. In the fall of 1965 it was disk-harrowed to establish uniform conditions. Slash pine seedlings (1–0) were outplanted at 1.2 × 1.2 m spacing in January 1966. Study plots were 6.1 × 6.1 m or 0.004 ha and contained 25 trees. Only the nine interior trees of each plot were measured.

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Treatments included fertilization, irrigation, and weed control, applied singly and in factorial combination as follows:

(1) Control—No treatment.
(2) Fertilization (*F*)—Prior to planting, ordinary superphosphate (291 kg P/ha) was applied in 0.8 m-wide strips and seedlings were planted down the center of the strips. One, 2, and 3 years after planting, ammonium nitrate (112 kg N/ha/yr) was applied in 0.8 m-wide strips on each side of the row of trees.
(3) Irrigation (*I*)—During each growing season (April–October) for 5 years, plots received at least 2.5 cm of water per week, either in the form of rainfall or as irrigation water from a sprinkler. During the remainder of each year (November–March), these plots received at least 2.5 cm of water (rainfall or irrigation) every other week.
(4) Weed Control (*WC*)—All competing vegetation was periodically removed (manually with a weeding hoe) each year. Competing vegetation usually occupied less than 1 percent of the plot and seldom reached a height of over 0.3 m.
(5) *F* + *I*—Plots received fertilizer as in (2) and water as in (3).
(6) *F* + *WC*—Plots received fertilizer as in (2) and weed control as in (4).
(7) *I* + *WC*—Plots received water as in (3) and weed control as in (4).
(8) *F* + *I* + *WC*—Plots received fertilizer as in (2), water as in (3), and weed control as in (4).

Treatments were replicated four times in a randomized complete block design.

Tree heights were measured after termination of the first and last growth flushes of each growing season from 1966 through 1970. Diameters (dbh) were measured at the end of the 1970 growing season. Stemwood volumes of the 5-year-old trees were estimated from volume tables prepared by Schmitt and Bower (1970).

Each winter from 1968 through 1970, foliar samples were collected from the first growth flush of the current year, dried at 70° C, and analyzed for total N, P, and K concentrations. Total foliar N was determined by the macro-Kjeldahl procedure modified to include nitrates; P and K determinations were made on dry-ashed (400° C) samples by colorimetric and flame emission procedures (Jackson 1958).

Daily records of rainfall and irrigation were maintained from April 1966 through December 1970. In May 1968, tensiometers calibrated to relate soil moisture suction with various soil water contents were placed in the rooting zone of selected plots. During May–August of 1968, changes in soil moisture were monitored to determine the effect of weed control and irrigation on available water status of the soil.

Effect of Treatments on Tree Growth

All cultural treatments, either singly or combined, resulted in significant increases in tree height, dbh, and volume growth (Table 1). Influence of treatments on tree growth for the duration of the study was proportional to the number of treatments applied. For example, any single treatment, the combination of any two treatments, or the combination of all three treatments resulted in proportional increases in tree growth.

Duncan's multiple range test of treatment means verified this effect and indicated that means could be separated into four distinct groups. These are: (1) untreated control trees, (2) trees receiving any single treatment, (3) trees receiving a combination of any two treatments, and (4) trees receiving a combination of all three treatments. Because this relationship existed for all variables tested, reference to treatments in future discussion will often be based on the number of treatments applied (single treatment, combined treatment, or complete treatment) rather than on the individual treatments.

Height Growth. All cultural treatments were responsible for significant annual increases in height growth throughout the

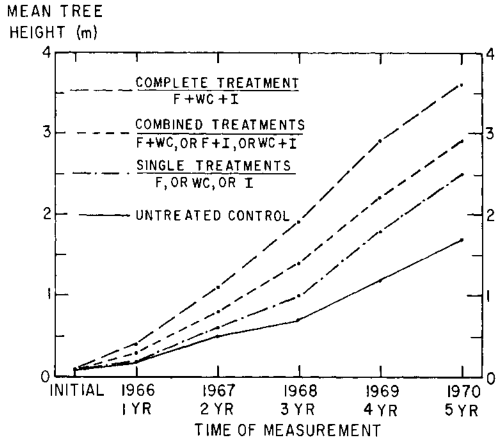

FIGURE 1. *Effect of intensive culture on height growth of slash pine.*

course of the study. After 5 years, mean tree heights ranged from 1.7 m for the control trees to 2.5, 2.9, and 3.6 m for trees receiving a single, combined, or complete treatment (Fig. 1).

Both fertilization and irrigation significantly increased growth of the first flush over that of the control throughout the duration of the study (Fig. 2), whereas weed control increased growth of the first flush only through the third year. Failure of fourth and fifth year response to weed control was probably due to natural reduction in herbaceous competition on all plots with advancing crown closure.

Of the three treatments, irrigation generally had the greatest influence on growth of the first flush. This response, which was associated with rainfall patterns in the area, suggests that deficient soil moisture in the fall and early spring was the major factor limiting first flush growth.

All three treatments, especially when combined, resulted in increases in growth of the subsequent or late flushes through the third year. During the fourth growing season, only fertilization and weed control affected elongation of the late flushes. The lack of response to irrigation during the

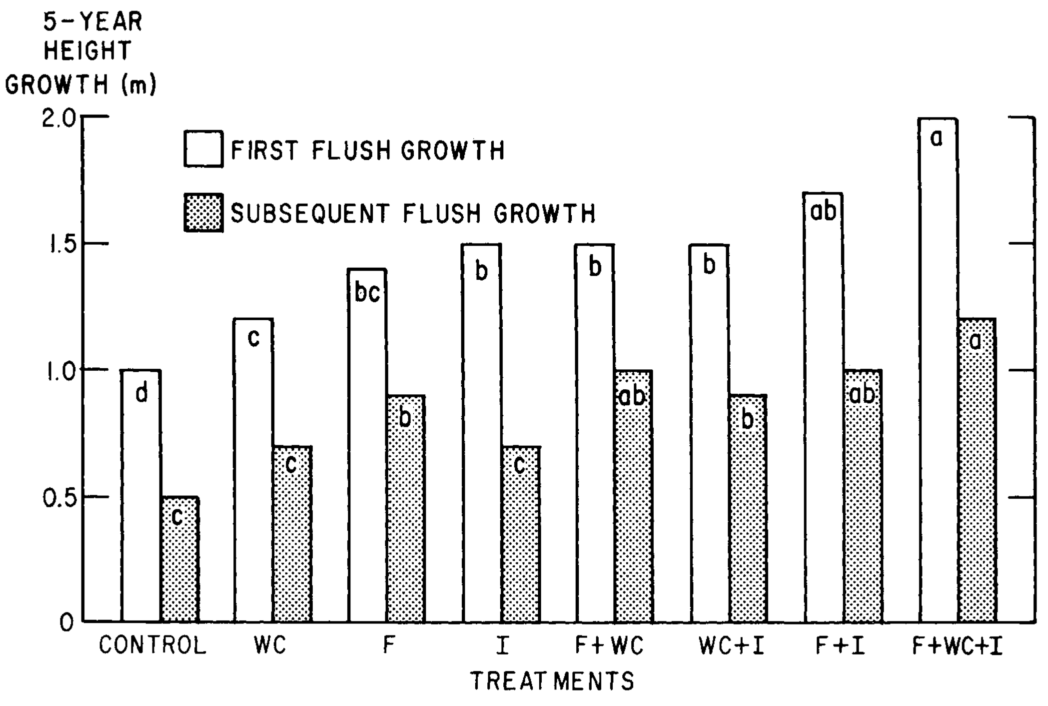

FIGURE 2. *Effect of intensive culture on 5-year height growth of slash pine by flushes (initial height at outplanting not included). Bars, which represent growth of the first flush and subsequent flushes for each treatment, not having the same letter are significantly different (p, 0.05).*

TABLE 1. Effect of intensive culture on growth of planted slash pine at age 5.[1]

Treatment	Mean tree height (m)	Mean tree diameter (cm)	Mean tree volume (cm^3)	Percentage increase over control		
				Height	Diameter	Volume
Control	1.7d	1.52d	821d	—	—	—
Single[2]	2.5c	3.05c	1,586c	47	101	93
Combined[3]	2.9b	3.81b	2,237b	71	151	172
Complete[4]	3.6a	5.08a	3,568a	112	234	335

[1] In the same vertical column, group means not followed by the same letter are significantly different (p, 0.05). Means of individual treatments within any group were not significantly different.
[2] Either fertilization (*F*), irrigation (*I*), or weed control (*WC*).
[3] Either $F + I$, or $F + WC$, or $I + WC$.
[4] $F + WC + I$.

fourth season can probably be explained by that year's above-normal rainfall. During the middle and latter part of the growing season (July–September), all plots received an unusually large amount of rainfall (89 cm compared to a mean for this period of 51 cm). In effect, the irrigation treatment was non-existent during this part of the growing season.

In contrast with growth of the first flush, late season growth (second and third flushes) was generally influenced most by fertilization (Fig. 2). This response indicates that, during the middle and latter part of the growing season, nutrients are the major factors limiting growth on these sites.

Diameter and Volume Growth. Tree diameter was increased by single and factorially combined treatments (Table 1). Any single treatment or any two combined treatments resulted in one-fold increases in diameter over the control, while the combination of all three treatments produced a two-fold increase in diameter. Fertilization, either alone or in combination with other treatments, was responsible for the greatest increases in diameter growth.

Tree volume was also affected by all treatments. Irrigation and fertilization had about equal influence. However, single, combined, and complete treatments resulted in one-, two-, and three-fold increases in volume over the control after five years.

Effect of Treatments on Nutrient Status of Trees

Nitrogen. Factorial combinations of treatments generally resulted in significantly lower N concentrations in current annual foliage in 1968 and 1969 (Table 2). The unusually low N concentration in the faster-growing trees receiving the complete treatment probably resulted from growth dilution, while the relatively high N level in the slower-growing trees receiving a single or no treatment was probably the result of an accumulation of N accompanied by poor growth.

TABLE 2. Effect of intensive culture on N status of young slash pine.[1]

Treatment	Foliar N concentration by sampling time In percent		
	1968	1969	1970
Control	1.22a	1.10ab	1.04b
Single[2]	1.18b	1.12a	1.05b
Combined[3]	1.08c	1.07bc	1.06b
Complete[4]	.94d	1.04c	1.09a

[1] In the same vertical column, group means not followed by the same letter are significantly different (p, 0.05). Means of individual treatments within any group were not significantly different.
[2] Either fertilization (*F*), irrigation (*I*), or weed control (*WC*).
[3] Either $F + I$, or $F + WC$, or $I + WC$.
[4] $F + WC + I$.

TABLE 3. Effect of intensive culture on P status of young slash pine.[1]

Treatment	Foliar P concentration by sampling time In percent 1968	1969	1970
Control	0.08bc	0.08b	0.07b
Single[2]			
F	.10a	.10a	.10a
I	.09ab	.08b	.07b
WC	.07c	.08b	.07b
Combined			
F + I	.10a	.10a	.10a
F + WC	.08bc	.09ab	.09a
WC + I	.07c	.08b	.07b
Complete			
F + WC + I	.08bc	.09ab	.09a

[1] In the same vertical column, group means not followed by the same letter are significantly different (p, 0.05).

[2] *F* = fertilization, *I* = irrigation, and *WC* = weed control.

TABLE 4. Effect of intensive culture on K status of young slash pine.[1]

Treatment	Foliar K concentration by sampling time In percent 1968	1969	1970
Control	0.61a	0.37a	0.31a
Single[2]	.60a	.33b	.28ab
Combined[3]	.56b	.28bc	.28ab
Complete[4]	.50c	.26c	.26b

[1] In the same vertical column, group means not followed by the same letter are significantly different (p, 0.05). Means of individual treatments within any group were not significantly different.

[2] Either fertilization (*F*), irrigation (*I*), or weed control (*WC*).

[3] Either *F + I*, or *F + WC*, or *I + WC*.

[4] *F + WC + I*.

Foliar N levels of fertilized and unfertilized trees changed, but in the opposite directions, as the trees became older. Foliar N concentrations of unfertilized control trees decreased each year from 1968 to 1970, while foliar N levels of trees that received the complete treatment increased during the same period. These trends suggest that the control trees depleted the available supply of N while the fertilized trees in the complete treatment accumulated N in response to the N applied in 1967, 1968, and 1969. The relatively comparable foliar N concentrations in 1970 also indicate that tissue N levels were approaching an equilibrium for that stage of growth.

Phosphorus. The P concentration of the foliage was dependent primarily on the fertilization treatment (Table 3). Fertilization resulted in slightly higher concentrations of foliar P through the fifth year (1970). The foliar P levels of control trees and trees receiving only irrigation dropped from 1968 to 1970, while P levels of fertilized trees tended to remain the same or increase slightly. These differences in foliar P were a response to the fertilizer P applied in 1966.

Potassium. Intensive cultural treatments resulted in lower concentrations of foliar K (Table 4). These differences, like those for N, probably resulted from growth dilution. Foliar K levels tended to decrease with time for all treatments and the control.

Effect of Treatments on Moisture Status of Soil

Soil moisture suction and corresponding soil water contents obtained from tensiometers provided an index from which comparative plant-soil-moisture relationships were developed daily. These relationships are summarized in Table 5.

Both weed control and irrigation increased available moisture in the soil, but irrigation had more effect. For example, during the 110-day monitoring period, trees on the control plots were under moderate to severe moisture stress 58 days or 53 percent of the time. However, during this same period, trees on weed-controlled and irrigated plots were under stress only 45 and 18 days, or 41 and 16 percent of the time.

On weed-controlled plots the soil not only received more water from light

TABLE 5. Plant-soil-moisture relationships during the 110-day monitoring period on the control, weed-controlled, and periodically irrigated plots. (In no. of days.)

Status	Control	Weed-controlled	Irrigated
No stress (field capacity, 100-percent available soil moisture)	52	65	92
Moderate stress (25-percent available soil moisture)	45	35	15
Severe stress (5-percent available soil moisture)	13	10	3
Total for growing season	110	110	110

showers (< 2 cm) than the control, because of less interception, but also retained the water longer and hence reduced the period of stress by 13 days or 12 percent. The effects of these benefits were reflected in the increase in first flush growth (Fig. 2).

Irrigation reduced the stress period by 40 days or 50 percent. Timing of application prevented irrigation from eliminating stress altogether. If, for example, irrigation water had been supplied on a plant-need basis rather than on an arbitrary weekly schedule, several periods of stress that occurred on the irrigated plots could have been reduced or eliminated.

Conclusions

Growth of slash pine planted on the droughty, infertile west Florida sandhills was improved in almost direct proportion to the number of treatments applied. Fertilization, irrigation, and weed control, applied singly and in factorial combination, resulted in 45-, 70-, and 110-percent increases in mean annual height growth, 100-, 150-, and 230-percent increases in dbh, and 100-, 170-, and 330-percent increases in stemwood volume after 5 years. Smith *et al.* (1972) also reported that irrigation and irrigation plus fertilization greatly increased growth of slash pine on excessively drained sands in central Florida. However, the best growth response occurred when fertilizers were applied in combination with the highest level of irrigation.

These results indicate that both available soil moisture and nutrients limit the growth of slash pine on these sites during various times of the year. Soil moisture deficiencies during the previous fall and current spring restrict first flush growth, while nutrient deficiencies limit growth of subsequent or late flushes as well as diameter (dbh) growth. In order to obtain a marked improvement in growth of slash pine on Lakeland sands, both the nutrient and moisture regimes of these soils must be improved.

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