Seed Germination and Seedling Establishment of Carya floridana (Sarg.) Small (Juglandaceae)

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Seed germination and seedling establishment of *Carya floridana* (Sarg.) Small (Juglandaceae)

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ABSTRACT

McCarthy, B. C. and D. R. Bailey (Department of Biology, Frostburg State University, Frostburg, MD 21532-1099). Seed germination and seedling establishment of *Carya floridana* (Sarg.) Small (Juglandaceae). Bull. Torrey Bot. Club 119: 384–391. 1992.—Seeds of *Carya floridana* (Sarg.) Small, a Florida endemic and prominent constituent of the southern ridge sandhill vegetation type, were collected from Red Hill at the Archbold Biological Station in Highlands County, Florida to determine germinability and microsite requirements for successful establishment, growth, and survival. A float test revealed that only 0.03% of the nuts were unsound (14 of 440). Of the remaining 426 nuts, 384 were selected for uniformity and returned to the greenhouse to determine germinability. A total of 368 nuts (96%) germinated within 20 days with no pretreatment. Germinated nuts were subsequently used to experimentally examine the effects of soil type (pure sand, sand : vermiculite, sphagnum : vermiculite : perlite) and nutrient addition (20:20:20 NPK fertilizer present or absent) on seedling establishment, growth, and survival. Survival was >90% after 12 weeks for all non-fertilized soil types and the fertilized sphagnum : vermiculite : perlite treatment. Fertilization of the sand and sand : vermiculite soils, however, resulted in survivorship declining to 38 and 0%, respectively. Soil, fertilizer, and the soil•fertilizer interaction had significant effects on many of the morphometric and allocation variables. In general, this species appears to be well adapted to soils with low water holding capacity, low organic matter, and minimal fertility. While fire is the primary determinant of seedling establishment and survival in this habitat, microsite heterogeneity may play a secondary role.

Key words: *Carya floridana,* Florida, germination, plant-soil relations, sandhill vegetation, seedlings.

Instability and late geologic development of the southern Lake Wales Ridge, combined with a pyrogenic disturbance regime, has resulted in a considerable number of endemic species in central Florida (Abrahamson 1984b). The evolutionary and ecological factors influencing the vegetation of the Lake Wales Ridge have attracted much attention and have been well studied by botanists and ecologists (e.g., Mulvania 1931; Laessle 1958; Abrahamson 1984a, 1984b; Abrahamson *et al.* 1984; Givens *et al.* 1984; Myers 1985; Peroni and Abrahamson 1986; Myers and White 1987; Myers 1990).

Soil-vegetation relationships and the effects of fire on community diversity and succession have historically been central issues regarding sandhill vegetation dynamics (see discussion by Myers 1985, 1990). While vegetation patterns have been well studied, there is still much to learn regarding the specific ecological requirements for the regeneration of individual plant species (Minno and Myers 1986). For example, the reproductive and regeneration ecology of the hickories (*Carya* spp.) has not been extensively and systematically examined (however, see McCarthy and Wistendahl 1988; McCarthy and Quinn 1989, 1990; and Myster and McCarthy 1989)—in particular, little is known about species of minor economic importance (e.g., *C. floridana*).

Carya floridana (Sarg.) Small (Florida scrub hickory) is a small tree or shrub in the Juglandaceae that is distributionally limited to central Florida (Small 1933). Observations suggest that *C. floridana* will become a prominent community constituent (10–20%) of the southern ridge sandhills vegetation type when fire has been suppressed for a number of years and where the soils are excessively well-drained and nutrient poor (Abrahamson *et al.* 1984). Scrub hickory also appears to be an aggressive invader of open xeric woodlands (Myers and White 1987) and its ability to resprout ensures its survival under the ambient disturbance regime (Abrahamson 1984b).

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Nutrient availability and water are likely to be prominent factors limiting seedling establishment, growth, and survival in this community type (Myers 1990).

We conducted a greenhouse study to examine the germination potential of seeds of *C. floridana* and investigate how soil type may interact with nutrient supply and moisture availability to determine seedling establishment, survival, and allocation patterns. *Carya floridana* nuts have a very high nutritional quality (Abrahamson and Abrahamson 1989) and information regarding their germination and establishment may prove useful for managing mast for fruit-eating animals. Perhaps more importantly, small-scale experiments with microsite conditions may provide additional insight into observed patterns of variability within a larger framework of successional dynamics (McCarthy and Facelli 1990).

Materials and Methods. SITE DESCRIPTION AND SEED COLLECTION. *Carya floridana* seeds were collected from southern ridge sandhill vegetation around Red Hill at the Archbold Biological Station (ABS), Highlands County, Florida (27°11′N, 81°21′W). The climate, soils, and vegetation of ABS have been described in detail by Abrahamson *et al.* (1984) and are summarized below.

The climate is characterized by hot, wet summers and mild, dry winters. Mean maximum summer temperatures range from 33.4 to 34.1°C; mean maximum winter temperatures range from 19.6 to 21.4°C. Mean soil temperatures at 5 cm can reach a maximum of 36.2°C in August and a minimum of 14.2°C in January. Mean annual rainfall at ABS averages 1374 mm with 61% falling between the months of June and September.

Soils of the Red Hill area are Entisols and classified as Astatula-Paola-Tavares (Carter *et al.* 1989). These soil series are Quartzipsamments which are excessively well-drained sandy soils (<5% silt and clay) having little organic matter (0.5–2.0%), a low to circumneutral pH (3.6–7.3), and are generally considered extremely nutrient poor (Carter et al. 1989).

The southern ridge sandhill community (Abrahamson *et al.* 1984), previously referred to as "Caribbean" pine-turkey oak by Laessle (1958) and slash pine-turkey oak by Douglass and Layne (1978), is a xeromorphic, pyrogenic vegetation type consisting of three layers: tree (3–10 m), shrub (0.3–3.0 m), and ground cover (<0.3 m). The tree layer forms an open canopy dominated by south Florida slash pine (*Pinus elliottii* var. *densa*), turkey oak (*Quercus laevis*), and scrub hickory (*Carya floridana*). The shrub layer is characterized by scrub oaks (*Q. myrtifolia, Q. geminata, Q. chapmanii*) and a variety of other broadleaf shrubs in addition to scrub palmetto (*Sabal etonia*) and saw palmetto (*Serenoa repens*). The ground layer is dominated by numerous herbaceous dicots, grasses, and sedges. Patches of lichens (*Cladonia* spp.) and bare sand are spread throughout the understory.

Freshly fallen *Carya floridana* seeds were collected on 20 January 1991. A total of 440 seeds were collected, washed, dried at room temperature, and stored in a cotton bag within an insulated cooler for two weeks. At the time of washing, seeds were allowed to stand for several minutes in a pail of water. Floating seeds were deemed unsound, the number recorded, and then discarded. All subsequent observations on seed germination and seedling growth and survival were conducted at the Frostburg State University greenhouse.

SEED AND SEEDLING EXPERIMENTS. In February, 384 of the remaining seeds were selected for uniformity in size and shape and directly planted into four flats (96 seeds each) containing Pro-Mix BX potting medium to determine germination potential. Flats were watered as needed. After 20 days seeds were examined for germination. Emergence of the radicle to a length at least as great as that of the seed was used as the criterion for germination.

Of the germinated seeds, 210 were randomly selected to be used in a greenhouse (12 hr/12 hr light/dark, temperature range 20–30°C) seedling experiment designed to assess the effects of soil type (water holding capacity) and nutrient availability on plant growth. The experiment utilized a completely randomized design varying soil type (3 levels) and fertility (2 levels). Germinated seeds were placed into 10 cm square pots containing either pure coarse sand (80 reps; to emulate normal field conditions), a 50:50 mix of sand : vermiculite (80 reps; to increase water holding capacity and nutrient adsorption), or Pro-Mix BX (50 reps; a soilless potting mix of sphagnum : vermiculite : perlite designed to emulate "maximal" soil moisture and fertility conditions). Half of the replicate seedlings of each soil type were randomly selected and designated to receive a weekly application of water soluble 20:20:20 N:P:K fertilizer (Peters) applied at the rate of 200 kg/ha. Seedlings not designated to receive fertilizer received a portion of water equal to that used

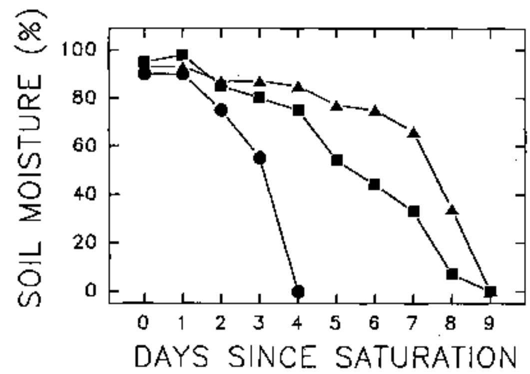

Fig. 1. Water regime for three soil types used in the greenhouse experiment of seedling establishment. Symbols: circles = sand, triangles = sand : vermiculite, squares = sphagnum : vermiculite : perlite. The water regime of the sand soil was significantly different ($P <$ 0.05, Mann-Whitney *U*-test) than the other two (which did not differ from each other).

in the fertilizer treatment. Seedlings were watered lightly one other time each week to prevent drought death. Seedlings were completely randomized on the bench every 2 weeks.

To verify the influence of soil type on water regime, we measured changes in percent soil moisture in a separate experiment. Eighteen pots were arrayed such that there were six rows of each of the three soil types. The pots were then saturated with water and three gravimetric soil moisture measures made from one pot of each soil type every 24 hr for 6 days.

Seedlings of the six treatment combinations were monitored weekly to evaluate survival. Presence of an aboveground shoot was used as the criterion for survival. This criterion is the only practical one to use; however, it may not always reflect true "survival" in a sprouting species where the shoot system can die back repeatedly while maintaining a functional root system. Thus, we chose to evaluate "stem survival" during the course of the experiment and a one-time measure of "absolute survival" at the end of the experiment when seedlings were harvested.

After 12 wk, the experiment was terminated (seedlings ceased height growth after 9 wk). Seedlings were washed and divided into parts: primary root (tap), secondary (and higher order) roots, leaves, and stem. At the time of harvest, data were collected on the number of leaves per seedling, primary root length and stem length using a ruler (mm), and maximum root width and basal stem diameter using a micrometer (mm). Plant parts were then air-dried in paper bags at 80°C for 5 days and biomass (g) determined for the primary root, secondary roots, stem, and leaves. Data were analyzed using two-way analysis of variance (Sokal and Rohlf 1981).

Results. Freshly collected seeds of *Carya floridana* were generally sound and contained a well-developed kernel. The float test indicated that 14 of 440 seeds (0.03%) were unsound. Of the remaining 426 seeds, 384 were selected for the germination test of which 368 (96%) germinated within 40 days. The ungerminated seeds were maintained in flats for an additional 17 weeks but all failed to germinate. There appears to be no need for pre-treatment (e.g., stratification) for adequate germination.

In the greenhouse analysis of soil moisture, we determined that the three experimental soil types dried down at different rates (Fig. 1). Specifically, the water regime of the pure sand treatment was different (dried down faster) than either the sand : vermiculite ($P = 0.07$) or sphagnum : vermiculite : perlite ($P = 0.05$) treatments (Mann-Whitney *U*-tests). The soil moisture in the sand : vermiculite and sphagnum : vermiculite : perlite soil types did not differ ($P = 0.25$). These data confirmed that soil type had a considerable effect on water holding capacity. Thus, we could examine seedling growth and survival in the greenhouse under moisture regimes that varied considerably from field ambient.

Seedling stem survival (Fig. 2) varied as a function of fertilization. Stem survival after 12 weeks was >95% for all unfertilized soils and no significant ($P > 0.5$) differences were observed among soil types (two sample proportion tests). Oddly, the addition of fertilizer reduced stem survival to 38% in sand soils and 0% in sand : vermiculite soils (both $P < 0.01$, fertilizer/no-fertilizer comparison). Fertilizer had little effect on the survival of seedlings in sphagnum : vermiculite : perlite soils (96% survival). Additionally, we determined at harvest that there was almost a complete correspondence between "stem survival" and "absolute survival." Only 2 seedlings in the sand treatment were found to have an intact functioning root system in the absence of an above-ground shoot system. We did note that numerous basal sprouts were present on many seedlings indicating that there was frequent stem dieback at the earliest period of establishment.

At the termination of the experiment (12 wk) 136 seedlings remained alive. However, one treatment combination (sand : vermiculite + fertilizer) had no surviving seedlings. To better assess the effects of all treatment combinations, we decided to assess seedling morphometrics and allocation patterns on all seedlings that were still alive as of week 8 (all plant parts were still present). Thus, 175 seedlings were analyzed, 10 of which belonged to the sand : vermiculite + fertilizer treatment (N = 24 to 40 in all other treatment combinations).

Seedling growth and allocation patterns differed significantly (MANOVA) as a function of soil type (Wilks' lambda = 0.34298, $P < 0.0001$), fertilizer treatment (Wilks' lambda = 0.25875, $P < 0.0001$), and soil × fertilizer interactions (Wilks' lambda = 0.44034, $P < 0.0001$). Subsequent two-way ANOVA's were applied to assess the source of variation among morphometric and allocation variables (Table 1).

Of the morphometric variables, the number of leaves, maximum root diameter, and basal stem diameter were influenced more by fertilization than by soil type (Table 1). Fertilization resulted in an overall decrease in the number of leaves, root diameter, and stem diameter. However, interactions were also present (Table 1). For example, the sphagnum : vermiculite : perlite soil with fertilizer resulted in a greater number of leaves rather than a lesser number as in the other two soil types (Fig. 3a). Variation in root length and stem length was primarily attributable to soil type (Table 1). The primary tap root was significantly ($P < 0.05$) shorter in the sand : vermiculite treatment (Fig. 3c). Stem length was significantly ($P < 0.05$) greater in the sand treatment (Fig. 3e).

Among the biomass allocation variables, the addition of fertilizer resulted in significant differences for all but leaf biomass (Table 1). Soil type was also responsible for a considerable degree of variation, particularly for secondary root biomass, stem biomass, and leaf biomass (Table 1). All allocation variables exhibited significant ($P < 0.05$) soil × fertilizer interactions (Table 1).

Among the six treatment combinations, root : shoot ratios varied from a low mean (± SE) of 1.78 (± 0.40) for the sphagnum : vermiculite : perlite with fertilizer treatment to a high mean of 4.21 (± 0.61) for the sand : vermiculite with fertilizer treatment. The overall mean root : shoot ratio was 2.66 (± 0.25, N = 173).

With root : shoot ratios approaching 3:1, total seedling biomass is influenced considerably by root biomass. A comparison of Fig. 3h–i with 3j confirms this relationship. Fertilization accounted for much of the variance observed in allocation to primary and secondary roots (Table 1 and Fig. 3h–i), however, this relationship held only for seedlings with sand as a primary soil constituent (Fig. 3h–i). Stem biomass was greatest ($P < 0.05$) in pure sand soil and significantly depressed ($P < 0.05$) in fertilized sand : vermiculite soil (Fig. 3f). Leaf biomass did not exhibit an overall fertilizer effect, however, there was a significant decrease ($P < 0.05$) in leaf biomass for seedlings grown in sand : vermiculite soil with fertilizer (Fig. 3g).

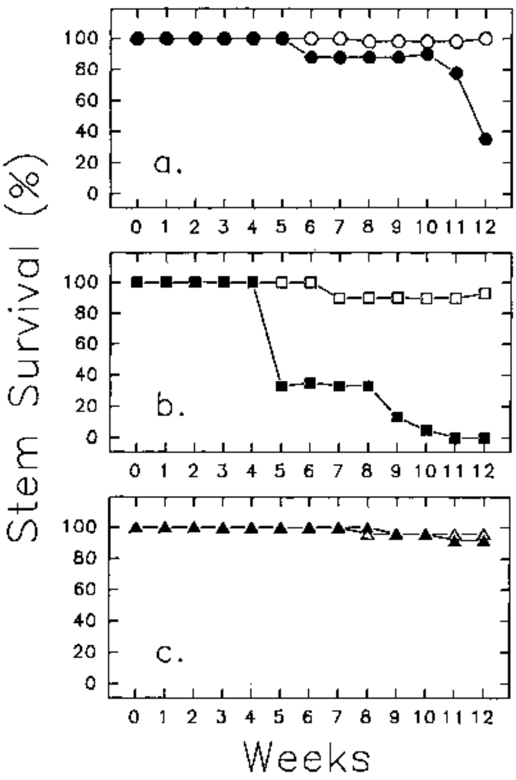

Fig. 2. Percent stem survival for sand soil treatment (a), sand : vermiculite treatment (b), and sphagnum : vermiculite : perlite treatment (c). Filled symbols designate fertilizer addition, hollow symbols designate no fertilizer addition. See text for sample sizes and statistical comparison of each treatment combination.

Discussion. As expected, seed germination in *Carya floridana* is quite unlike that of many of its northern congeners. Dormancy, caused largely by conditions in the embryo, is common throughout the commercial hickories of the eastern deciduous forest (U.S.D.A. 1948). Typically, 90–150 days of cold stratification are required to break dormancy and initiate germination. For

Table 1. Analysis of variance results for *Carya floridana* seedlings subjected to 3 soil types (sand, sand: vermiculite, sphagnum : vermiculite : perlite) and 20:20:20 NPK fertilizer (with or without).

Variable	Source	df	SS	F	*P*
No. of leaves	Soil	2	1.28	0.71	0.494
	Fertilizer	1	8.38	4.63	0.033
	Soil × Fert.	2	11.04	6.09	0.003
Max. root diameter	Soil	2	2.62	1.16	0.316
	Fertilizer	1	5.02	4.45	0.037
	Soil × Fert.	2	3.15	1.40	0.250
Primary root length	Soil	2	318.18	10.57	<0.001
	Fertilizer	1	0.05	0.00	0.957
	Soil × Fert.	2	12.47	0.41	0.662
Basal stem diameter	Soil	2	0.71	1.36	0.259
	Fertilizer	1	7.62	29.15	<0.001
	Soil × Fert.	2	2.35	4.50	0.013
Stem length	Soil	2	143.76	30.48	<0.001
	Fertilizer	1	1.76	0.75	0.389
	Soil × Fert.	2	5.84	1.24	0.292
Secondary root biomass	Soil	2	0.01	6.01	0.003
	Fertilizer	1	0.07	80.36	<0.001
	Soil × Fert.	2	0.03	16.22	<0.001
Primary root biomass	Soil	2	0.06	1.04	0.357
	Fertilizer	1	0.82	28.69	<0.001
	Soil × Fert.	2	0.55	9.70	0.001
Stem biomass	Soil	2	0.02	15.07	<0.001
	Fertilizer	1	0.01	6.27	0.013
	Soil × Fert.	2	0.01	3.14	0.046
Leaf biomass	Soil	2	0.12	6.25	0.002
	Fertilizer	1	0.01	0.10	0.757
	Soil × Fert.	2	0.20	10.41	<0.001
Total biomass	Soil	2	0.33	2.52	0.084
	Fertilizer	1	1.41	21.37	<0.001
	Soil × Fert.	2	1.48	11.18	<0.001

example, only 26% of *C. ovata* seeds germinated without stratification as compared to 70% for those receiving 60 days of stratification at 3°C (Barton 1936). The seed dormancy trait seems to have been lost from *C. floridana*. The absence of a sufficiently long and/or cold stratification period in central Florida during the winter may limit the southern distribution of other *Carya* species and define the range of *C. floridana*. The only obvious requirement for seed germination in *C. floridana* seems to be sufficient moisture for imbibition. This moisture is likely to be available in the early summer rainy season in south central Florida (Abrahamson *et al.* 1984). The high percentage of germination in *C. floridana* (93%) is also notable in that it is well above the average of 50–80% observed in other congeners (U.S.D.A. 1948; personal observation).

While it was not our intent to examine nut quality in this study, the small proportion (0.03%) of underdeveloped and/or unsound nuts is somewhat unusual among *Carya* species (as a caveat, there may have been some unconscious decisions made during field collection). Boucher and Sork (1979) noted a very high proportion (ca. 90%) of underdeveloped, aborted, and insect-infested nuts of *C. glabra* in a Michigan oak-hickory forest. Fruit abortion and weevil infestation in *Carya* seems to vary widely (<5% to >95%) throughout a species' range and population (BCM personal observation). The limited and isolated range of *C. floridana* has possibly led to a greater degree of protection from predatory curculionid weevils common in the eastern U.S.

Soils undoubtedly have a role to play in the distribution and abundance of scrub vegetation in general as well as that of *Carya floridana* in particular. This influence may be manifested at differing scales (from many km^2 to several cm^2). Typically, the Quartzipsamments of the southern

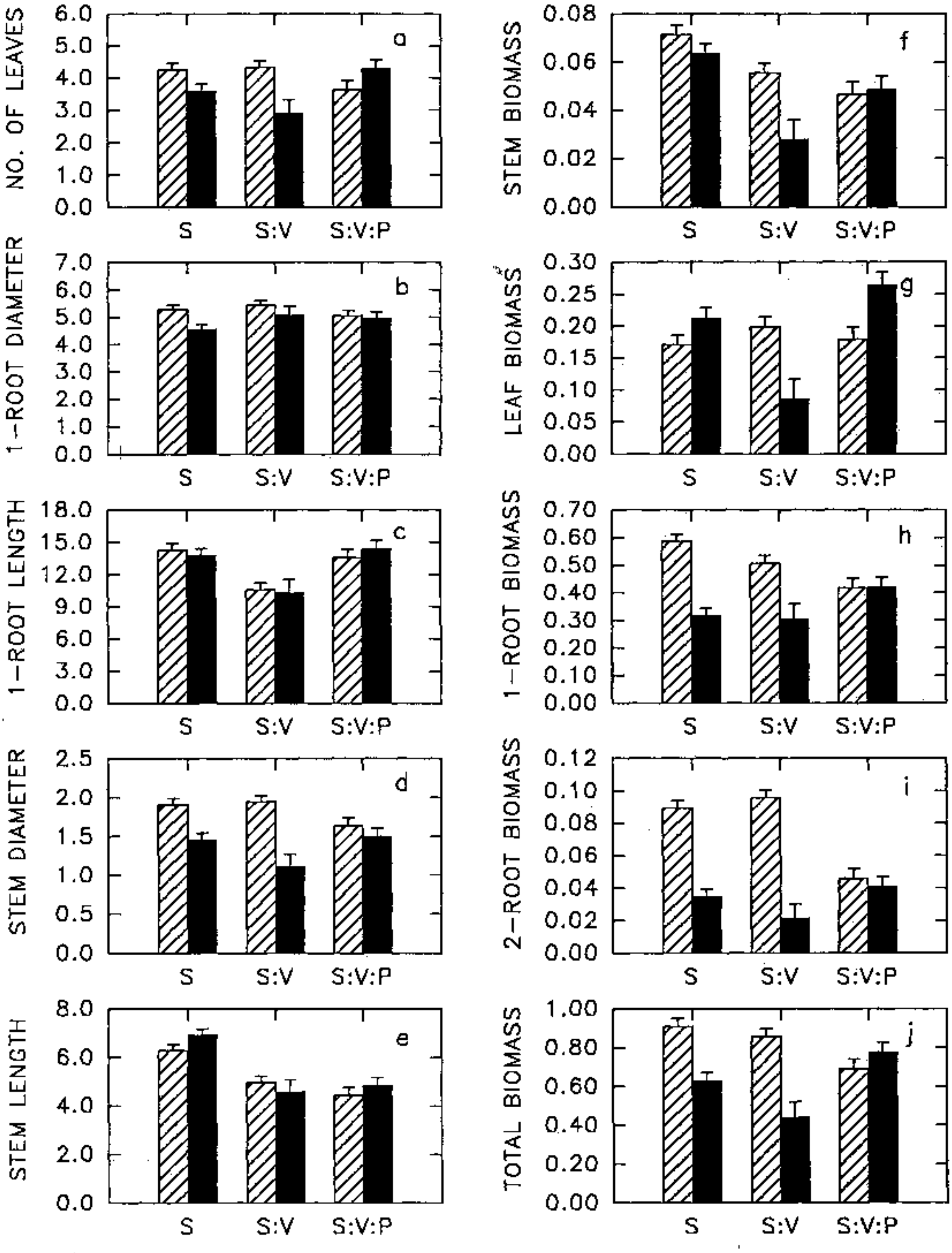

Fig. 3. Mean (± SE) values of morphometric (a–e) and biomass (f–j) variables (1 = primary, 2 = secondary and higher order) from seedlings grown under different experimental treatments in the greenhouse. Lengths and diameters are in millimeters and biomass measures in grams. Soil types: S = sand, S:V = sand : vermiculite, S:V:P = sphagnum : vermiculite : perlite. Hatched bars = no fertilizer added, filled bars = fertilizer added.

ridge sandhills have little if any horizon development, but do maintain a considerable degree of variability from leached white sands to unleached grayish brown sands (Myers 1990). Associated with this soil color variation are small differences in extractable bases, organic matter, pH, and water content (Carter *et al.* 1989). Conventional wisdom suggests that different vegetation has developed on different soils; however, Myers (1990) suggests that the color of a scrub soil more likely reflects the length of time that scrub vegetation has occupied the site.

Given the ambient soil conditions, the most obvious hypothesis is that drought and nutrient deficiency caused by quartz sands limit the distribution of *Carya floridana* on a regional scale and that soil heterogeneity influences distribution in a spatially explicit manner at a much smaller scale. Our greenhouse experiment with different soil types (each with an inherent moisture regime) and fertility confirms that *C. floridana* performs best under conditions that emulate field ambient. Survival of seedlings was 99% in unfertilized sandy soils. Our sand had 0% organic matter and extremely low water and nutrient holding capacity. Comparison of survival rates across all three soil types, possessing different water moisture regimes, indicated no difference ($P > 0.50$) suggesting that water may not be limiting establishment or survival. Interestingly, the addition of fertilizer resulted in a decline in survival on sandy soils (both with and without vermiculite) suggesting that soil nutrients (at least N, P, or K) may also not be limiting seedling establishment. One possible explanation might be that the solute content of the fertilized water, combined with droughty soils for the sand treatment, caused root tissue mortality and/or decreased ability of the root system to absorb water against a solute gradient. However, we did not observe any root necrosis at harvest or increased survival of the sand : vermiculite treatment. In fact, the sand : vermiculite treatment with increased water holding capacity (relative to pure sand) exhibited the greatest mortality.

The analysis of growth and biomass allocation followed a similar trend as survival, but factors sometimes interacted in a complex manner. In general, stem length and biomass, as well as root length and biomass, were greatest on sandy soils. Our addition of vermiculite to sand (to increase water holding capacity) did not have a significant effect on most growth parameters. Primary root length was one of the few growth variables to be significantly affected by this soil treatment (probably resulting from differential allocation to secondary roots; Fig. 3c, h–i). The length of the primary root may be critically important to the survival and growth of many scrub species (Myers 1990). Hickories have some of the longest tap roots observed among eastern hardwoods (Boisen and Newlin 1910). Leaf parameters (number and biomass) were the only variables that significantly responded to the addition of nutrients. These parameters are probably much less important to the survival of the seedling relative to root length and biomass allocation. The ability of *Carya* spp. to resprout repeatedly under heavy disturbance makes an intact root system much more valuable than the shoot system to the ultimate survival of the plant (Boisen and Newlin 1910; Monk 1981).

At a regional scale, the range of *Carya floridana* is likely influenced by edaphic and climatic conditions. At a much smaller scale (microsite), soil moisture, fertility, and organic matter do not appear to have a pronounced effect on seedling establishment, growth, or early survival. Seedlings are most likely relying solely on stored seed reserves. The regeneration niche (sensu Grubb 1977) of *C. floridana* is such that only a limited number of woody species possess the adaptations necessary to coexist under such site conditions. The role of fire in this ecosystem may be more important than microsite heterogeneity in determining species coexistence and regeneration patterns.

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