THE RELATIONSHIP BETWEEN SOILS AND FOLIAR NUTRITION FOR PLANTED ROYAL PAULOWNIA

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Abstract—Royal paulownia is becoming an important hardwood plantation species in the southern U.S. A study was done to investigate two novel site preparation techniques for aiding the establishment of royal paulownia seedlings in the Virginia Piedmont. The effects of these treatments on the foliar nutrition of first year seedlings was determined, as was the relationship between soil fertility levels and foliar nutrition in the three study blocks. Seedlings established following both trenching and subsoiling treatments had significantly higher levels of foliar P than the control seedlings. Seedlings growing in the trenched plots had higher levels of foliar N than the control seedlings. For example, the seedlings growing in the trenched plots had average foliar N levels of slightly over 25,000 mg/kg, while the control seedlings had levels of 17,250 mg/kg. The seedlings in control plots also had lower, but not significantly so, foliar levels of K, Ca, Fe, and Mn. Soil fertility levels, based on soil test measurements, had positive and significant relationships with the foliar nutrient levels, as determined by simple linear regression.

INTRODUCTION

Royal paulownia (*Paulownia tomentosa* (Thurb.) Steud.) is becoming an important hardwood plantation species in the Southern U.S. Originally introduced to the U.S. from China in the early 1800's, royal paulownia has become naturalized throughout much of the eastern U.S. Today the markets for paulownia wood remain in Japan, where the wood is used for a variety of products, including lumber for furniture, handicrafts, musical instruments, shoes, etc. (Hardie and others 1989). Landowners are interested in techniques for establishing and growing paulownia tree crops for the export market (Johnson and others 1992, Kays and others 1998).

This study was established to investigate the usefulness of two novel site preparation techniques, trenching and subsoiling for early establishment and growth of royal paulownia. Paulownia growth is best in China on light textured soils, with clay contents less than 10 percent (Zhao-Hua and others 1997). The heavy textured soils found in the Piedmont have proven problematic for paulownia establishment, survival, and growth. One aspect of paulownia field performance, foliar nutrition, will be reported here.

METHODS

Study Area

The study was established at Virginia Tech's Reynolds Homestead Forest Resources Research Center located in the Piedmont physiographic province in Patrick County, Virginia (latitude 36°40′N, longitude 80°10′W). Three abandoned agricultural fields were selected for the study sites, with each field representing a complete block. All three fields were in grass and broad-leaved weed cover.

The study area experiences a warm, humid continental climate, with a mean annual temperature of 15°C, mean annual precipitation of 114 cm, and mean growing season precipitation of 79 cm. Temperatures typically range from -1°C in winter to 29°C in summer. The normal growing season length is 190 days, with April 20 as the most likely date of the last killing frost in the spring, and November 1 as the most likely date of the first killing frost in the fall.

Soils in the study area are in the Cecil series, and are clayey, kaolinitic, thermic Typic Hapludults. These soils are deep and well-drained, and formed in weathered granite gneiss, quartz schist, and quartzite. The A horizons are thin to absent due to surface erosion when the fields were in agricultural production.

Seedling Propagation

Seed pods were collected from selected wild trees growing in southwestern Virginia and air-dried, and then seeds were extracted and stored in sealed containers at 4°C. In the late summer of 1993, seeds were broadcast sown in greenhouse flats containing a 1:1 by volume mixture of Pro-Mix BX® and sand. Following germination, the germinants were manually transplanted into cone-tainers, with two to four germinants per pot. The seedlings were grown in a heated (temperature above 15°C) greenhouse under

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Table 1—Soil chemical properties for each site preparation treatment in each block at the Reynolds Homestead Forest Resources Research Center

Block	Site Preparation Treatment	pH	Anaerobically Mineralized N (mg/kg)	Total N (mg/kg)	Total C (%)	Extractable (mg/kg)					
						P	K	Ca	Mg	Fe	Mn
	Subsoil	5.7	24.0	636	0.98	0.12	40.6	420.5	157.4	1.83	16.9
1	Trench	5.4	23.7	705	1.06	0.12	32.8	415.9	77.2	1.00	50.2
	Control	5.5	32.8	776	1.16	0.12	61.9	430.2	145.0	1.49	35.6
	Mean	5.5	26.8	706	1.07	0.12	45.1	422.2	126.5	1.44	34.2
	Subsoil	5.7	26.4	701	1.16	0.12	31.2	394.0	122.9	2.20	7.3
2	Trench	5.5	20.6	619	0.95	0.12	25.0	374.9	130.9	5.89	4.8
	Control	5.4	18.6	617	0.96	0.12	20.3	421.5	143.1	4.24	4.7
	Mean	5.5	21.8	646	1.02	0.12	25.5	396.8	132.3	4.11	5.6
	Subsoil	5.4	31.5	598	1.05	0.97	81.9	314.7	112.0	2.90	6.7
3	Trench	5.7	39.1	651	1.01	2.31	99.8	410.5	143.8	2.58	7.9
	Control	5.6	51.1	708	1.05	4.18	89.8	359.3	116.0	3.48	8.9
	Mean	5.5	40.5	652	1.03	2.49	90.5	361.5	123.9	2.99	7.8

natural light conditions, with water and nutrients added regularly, for 14 weeks. After 3 weeks, the most vigorous seedling in each pot was selected and the others were removed. Following the 14-week greenhouse period, the pots were moved outside to a slathouse and allowed to harden off until planting.

Site Preparation and Plantation Establishment

During the early spring of 1994, three site preparation treatments were installed on 0.05-ha plots in the three blocks. Treatment one consisted of drawing a single subsoil shank behind a tractor on a 2-m x 2-m grid throughout the block. The subsoil shank penetrated to a depth of approximately 75 cm, creating a grid pattern. Treatment two consisted of creating a 2-m x 2-m grid of 10 cm-wide x 60 cm-deep trenches throughout the block. The trenches were filled with soil and two loblolly pine (*Pinus taeda*) poles placed at depths of 40 and 25 cm. The pine poles were cut from a thinning operation in a nearby plantation. The purpose of both the subsoil and trenching treatments was to break up the dense subsoil and create

Table 2—Soil physical properties for each site preparation treatment in each block at the Reynolds Homestead Forest Resources Research Center

Block	Site Preparation Treatment	Bulk Density (g/cm^3)	Soil Strength (kg/cm^2)	Soil Moisture (%)	Coarse Fragments (%)	Sand (%)	Silt (%)	Clay (%)	Textural Class
	Subsoil	1.2	4.99	35.0	0.7	35	28	37	clay loam
1	Trench	1.4	8.44	25.8	0.8	40	23	38	clay loam
	Control	1.2	5.48	32.0	0.6	38	28	34	clay loam
	Mean	1.3	6.33	30.9	0.7	38	26	36	clay loam
	Subsoil	1.4	9.42	20.6	12.4	44	22	34	clay loam
2	Trench	1.3	7.87	21.2	5.9	47	20	34	sandy clay loam
	Control	1.5	7.38	21.2	12.1	46	19	37	sandy clay loam
	Mean	1.4	8.23	21.0	10.1	46	20	35	clay loam
	Subsoil	1.6	8.86	21.0	17.6	38	32	31	clay loam
3	Trench	1.5	7.95	21.6	15.1	42	28	31	clay loam
	Control	1.6	9.35	22.2	25.5	46	26	29	clay loam
	Mean	1.6	8.72	21.6	19.4	42	29	30	clay loam

Table 3—Foliar nutrient levels for each site preparation treatment in each block at the Reynolds Homestead Forest Resources Research Center

Block	Site Preparation Treatment	N	P	K	Ca	Mg	Fe	Mn
		Foliar Nutrient Level (mg/kg)						
	Subsoil	14,800	1,420	7,790	10,940	3,090	218	24
1	Trench	24,500	1,700	9,820	8,550	2,870	82	53
	Control	17,000	1,400	9,020	7,910	2,890	103	22
	Mean	18,800	1,510	8,880	9,130	2,950	134	33
	Subsoil	21,900	1,360	8,670	7,600	3,380	59	21
2	Trench	22,700	1,450	7,710	7,540	3,680	80	20
	Control	12,900	1,010	5,140	6,350	2,630	229	16
	Mean	19,200	1,270	7,170	7,160	3,230	123	19
	Subsoil	29,600	3,540	14,240	5,070	3,680	65	20
3	Trench	28,000	3,290	12,890	6,480	3,950	64	20
	Control	21,900	2,590	10,980	7,140	4,050	72	19
	Mean	26,500	3,140	12,700	6,230	3,890	67	20

root channels for the planted seedlings. The final site preparation treatment consisted of a control.

During May of 1994, 100 containerized royal paulownia seedlings were hand-planted on a 2-m x 2-m grid in each of the site-prepared plots, at the intersections of the subsoil channels or the trenches. In the control plots, the planting spots were hand-scalped, but this was not necessary in the site-prepared plots since there was adequate surface disturbance to remove the sod cover. As a secondary treatment, each plot was split into two subplots, and 50 seedlings in each subplot were surrounded with a 91-cm x 91-cm Vispore® weed mat. An additional 50 seedlings were left untreated.

Soil Sampling and Field Measurements

Prior to the installation of site preparation treatments, soil characterization samples were collected from each of the 18 subplots in the study. Five 30 cm-deep push tube samples were collected from random locations in each subplot, then composited in the field.

Simultaneously with the collection of samples for soil characterization, soil moisture samples were collected at the same five locations, to a depth of 15 cm. These samples were likewise composited and returned to the lab for gravimetric analysis. Comparative soil strength measurements were also obtained at the same locations, using a SOILTEST penetrometer to a depth of 5 cm. Additionally, three randomly located bulk density samples, to a depth of 5 cm, were collected in each subplot using an AMS soil core sampler.

Following installation of the site preparation treatments, gravimetric soil moisture samples were collected again from five random locations within each subplot. Soil penetrometer measurements were also repeated. In the control plots, five readings were made in random locations

Table 4—Site preparation treatment effects on royal paulownia foliar nutrient levels

Site Preparation Treatment	N	P	K	Ca	Mg	Fe	Mn
	Foliar Nutrients (mg/kg)						
Subsoil	22,100 ab[1]	2,110 a	10,240 a	7,870 a	3,380 a	114 a	21 a
Trench	25,100 a	2,150 a	10,140 a	7,520 a	3,500 a	75 a	31 a
Control	17,300 b	1,670 b	8,380 a	7,140 a	3,190 a	135 a	19 a

[1]Means followed by the same letter are not significantly different at the 0.10 level.

within each subplot. In the site-prepared plots, five readings per subplot were randomly taken in the subsoil channels and trenches, as well as in the undisturbed portions of the subplots. Likewise, the bulk density sampling was repeated in a fashion similar to the penetrometer measurements, except three bulk density samples were collected from each of the disturbed and undisturbed areas of the site-prepared subplots.

Foliar Sampling

During September 1994, sun leaves from four randomly selected seedlings in each site preparation treatment within each block were harvested and allowed to air-dry in paper bags.

Laboratory Methods

The characterization soil samples were air-dried and ground to pass a 2-mm sieve. Available P, K, Ca, Mg, Fe, and Mn were extracted using the dilute double-acid procedure with 0.05N HCl and 0.025N H_2SO_4 (Kuo 1996), with the extract analyzed using a Jarrell-Ash ICAP-9000 inductively coupled plasma emission spectrometer. An estimate of nitrogen availability was determined using the anaerobic incubation technique (Keeney 1982). Total nitrogen was determined using the micro-Kjeldahl method (Bremner and Mulvaney 1982). Soil pH was determined using a glass electrode in a 2:1 soil:water mixture. Percent organic carbon was determined using a LECO CR-12 carbon analyzer, and particle size analysis was conducted using the hydrometer method. Bulk density was determined gravimetrically, with correction for coarse fragments greater than 2 mm.

Foliage was oven-dried to a constant weight at 65°C, then ground in a Wiley mill to pass a 1-mm sieve. The ground tissue was dry-ashed in a muffle furnace at 500°C, dissolved in 6N HCl and analyzed for P, K, Ca, Mg, Fe, and Mn using a Jarrell-Ash ICAP-9000 inductively coupled plasma emission spectrometer. Total nitrogen was determined using the micro-Kjeldahl method (Bremner and Mulvaney 1982).

Statistical Analysis

This study was established as a randomized complete block, split-plot design, with site preparation treatments as major plots and a weed control mat treatment comprising the minor plots. There were three major plot site preparation treatments (subsoil, trench, and control) randomly applied in each of the three blocks, and two weed control treatments (mat or no-mat) applied to two subplots within each major plot. Thus, there were three blocks, three plots per block, and two subplots per plot. Each subplot had 50 seedlings. All measurements were averaged at the subplot level to create the experimental unit.

Foliar nutrient levels were subjected to an analysis of variance, followed by Duncan's Multiple Range Test at the 0.10 level. The analysis of variance revealed no effect of the weed control mats, so this factor was dropped from further analysis. Soil and foliar nutrient levels were compared using simple linear regression analysis.

RESULTS AND DISCUSSION

Soil Properties

Soil chemical and physical properties are displayed in tables 1 and 2. All three blocks had similar pH levels, with 5.5 being the average for each block. Block 1 tended to have slightly higher levels of total soil N, although Block 3 had the highest level of anaerobically mineralized N, at 40.5 mg/kg. Total C levels ranged from 1.02 to 1.07 percent. Levels of soil P were quite low on Blocks 1 and 2, averaging only 0.12 mg/kg. Soil P in Block 3 averaged 2.49 mg/kg. Block 3 tended to be richer also in soil K. Bulk densities tended to be consistent across the blocks, ranging from 1.3 g/cm^3 in Block 1 to 1.6 g/cm^3 in Block 3 (table 2). On the date that soil moisture was sampled, Block 1 had comparatively higher levels, at 30.9 percent compared to 21.0 and 21.6 percent for Blocks 2 and 3, respectively. Block 1 also had much lower levels of coarse fragments, with only 0.7 percent by weight. Blocks 2 and 3 averaged 10.1 and 19.4 percent, respectively. Across the study area the predominant soil textural class was clay loam (table 2).

Foliar Nutrient Levels

Foliar nutrient levels for the sampled seedlings are presented in table 3. Some block to block differences were noted, as well as differences between the treatments (table 4). Foliar N levels ranged from 18,800 to 26,500 mg/kg (table 3). P levels ranged from 1,270 to 3,140 mg/kg. N, P, and K foliar levels were considerably higher in Block 3, which relates well to the soil fertility levels shown in table 1.

Treatment effects on foliar nutrient levels were noted with only two nutrients, N and P (table 4). For N the seedlings growing on the trenched plots had significantly higher levels than the control seedlings. The seedlings growing on the subsoiled plots had intermediate levels, but they were not significantly greater than the control seedlings. Foliar N levels ranged from a low of 17,300 mg/kg for the control seedlings to 25,100 mg/kg for the seedlings growing on the trenched plots. For foliar P, both site preparation treatments led to seedlings with significantly higher levels than the control seedlings (table 4). The range in foliar P was from 1,670 mg/kg for the control seedlings to 2,150 mg/kg for the seedlings growing in the trenched plots. No significant differences were noted for any of the other treatments.

Relationship Between Soil Fertility and Foliar Nutrient Levels

The relationship between soil fertility and royal paulownia foliar nutrition is shown graphically in figure 1. Soil nutrient levels were regressed against the foliar nutrient levels for N, P, K, and Ca. Data were pooled at the block level, since soil sampling did not match the root zone of the individual seedlings from which leaf samples were collected. Therefore, the data set is limited to the averages of the soil samples and leaf samples for the three blocks. Nevertheless, strong and positive correlations were determined for all of the nutrients studied. Coefficients of determination ranged from a low of 0.911 for N to a high of 1.00 for K (figure 1). The inference is that royal paulownia is quite

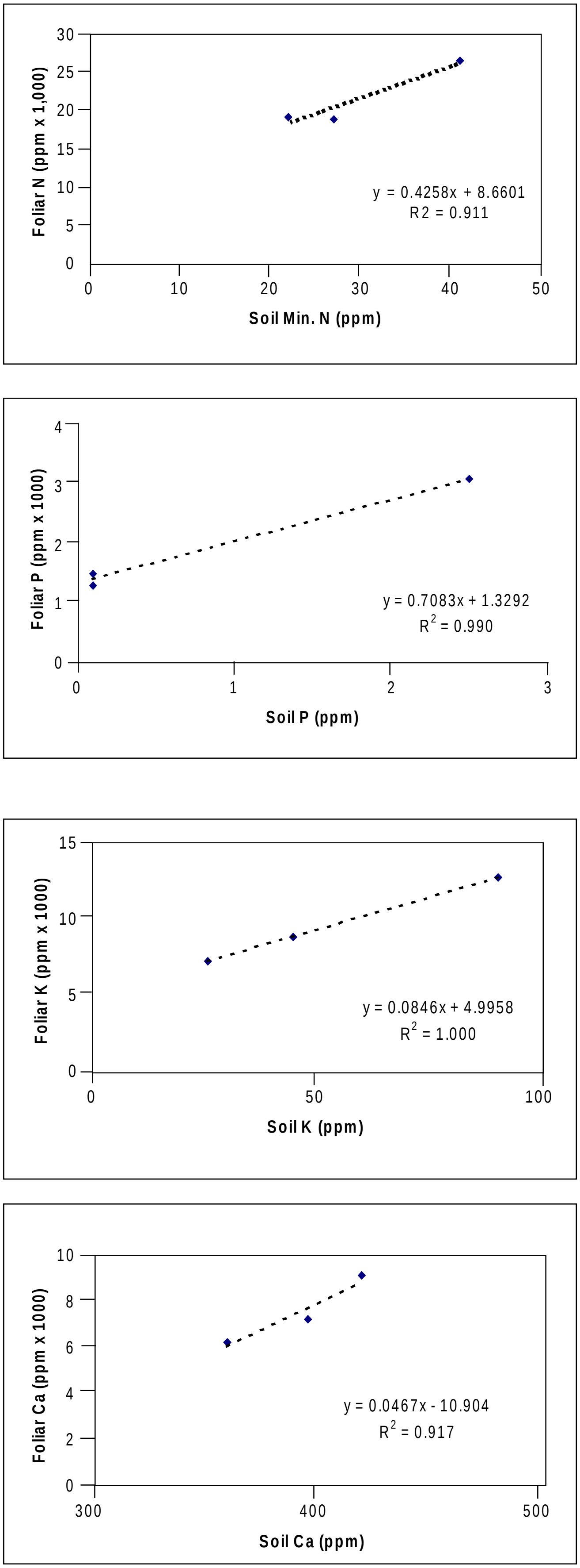

Figure 1—Relationships between soil fertility and royal paulownia foliar nutrition levels.

sensitive to soil fertility, a point that has been noted by others (Beckjord and McIntosh 1983, Graves and Stringer 1989). Although information on fertilizer regimes for royal paulownia are not well developed, it is apparent that foliar nutrition is closely related to soil nutrient levels, and fertilizer additions may be used to correct deficiencies. None of the seedlings in this study exhibited characteristic foliar nutrient deficiencies. Although leaf weights were not determined, royal paulownia seedlings and saplings are noted for having very large leaves. This indicates that on a total weight basis, paulownia may be quite demanding of nutrients. Foliar nutrition is also closely related to plant growth, so it is important to correctly balance foliar nutrient concentration (reported here) and nutrient content (Haase and Rose 1995, Cornelissen and others 1997).

CONCLUSIONS

Foliar nutrient levels for first year royal paulownia seedlings growing in plots of three different site preparation treatments were reported here. The treatments increased foliar concentrations of N and P, but did not affect foliar K, Ca, Mg, Fe, or Mn. Strong, positive correlations were found between soil fertility (expressed as extractable soil nutrients, or, in the case of nitrogen, anaerobically mineralizable) and foliar nutrient levels for N, P, K, and Ca. Royal paulownia appears to be quite sensitive to soil fertility, indicating that fertilization may be a viable treatment in areas of low fertility.

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