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richard e.
dickson

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The author, a Plant Physiologist, is headquartered at the Station's Institute of Forest Genetics in Rhinelander, Wisconsin.

North Central Forest Experiment Station
D. B. King, Director
Forest Service — U.S. Department of Agriculture
Folwell Avenue
St. Paul, Minnesota 55101

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THE EFFECTS OF SOIL MOISTURE, TEXTURE, AND NUTRIENT LEVELS ON THE GROWTH OF BLACK WALNUT

Richard E. Dickson

In recent years intensive management (including fertilization) of high value hardwoods has become an accepted forestry practice. The response of trees or tree seedlings to fertilizer depends on the soil's inherent nutrient level, texture, structure, and moisture, and the rate, time, placement, and kind of fertilization.

A study was designed to determine the response of black walnut seedlings to fertilization when grown in two Iowa soils of different texture, and to evaluate the interactions between water regimes and fertilizer rates.

PROCEDURES

Two soils, two soil moisture regimes, and three nutrient levels, were tested in a complete factorial design with three replications. The treatments were randomly assigned to pots kept in a single greenhouse bay. The treatment data were subjected to analysis of variance and Duncan's Multiple Range Test.

Soils

Samples of Ames clay loam (27 percent sand, 48 percent silt, and 25 percent clay) and Thurman sand (92 percent sand, 4 percent silt, and 4 percent clay) were collected from Boone and Story Counties, Iowa. The initial pH of the clay and sandy soil was 4.7 and 5.1 respectively, and did not change materially during the course of the experiment.

After thorough mixing, 11.80 kilograms of clay or 14.53 kilograms[1] of sand were placed in 3-gallon plastic pots. The field capacity and wilting point percentages were 40.0 and 12.6 percent for clay, and 25.0 and 2.7 percent for sand.

Soil Moisture Regimes

The two soil moisture regimes, field capacity and wilting point, were regulated by periodic weighing and rewatering of the entire soil-plant-pot system. After the amount of water required for a regime was lost from the system, the pot was rewatered to field capacity by weight for the start of another cycle.

The field capacity pots were rewatered every 2 or 3 days depending on the rate of water loss from the system. These pots were allowed to dry to approximately 75 percent of the available water then rewatered to field capacity.

The wilting point pots were allowed to dry from field capacity until the weight of the system reached that calculated for the 15 bar wilting point before rewatering for another cycle. Each wilting point cycle took approximately 20 days.

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[1] *These were the ovendry weights of each soil needed to provide 3.3 kilograms of available water per pot. Available water is the weight of water in the soil from the 1/3 bar field capacity to the 15 bar wilting point.*

Fertilizer Levels

The three treatments were: (1) no fertilizer; (2) N, P, K, at 137, 38 and 143 pounds/acre respectively (1X) added 27 days after planting; (3) N, P, K at same rates and time as treatment (2) plus N, P, K at double the initial level 30 days after initial fertilization – for a total 3X concentration (N, P, K at 411, 114, 429 pounds/acre).

Fertilizer levels were generated by adding 800 milliliters of a complete, concentrated Johnson's nutrient solution to each pot.[2]

Planting and Harvesting

Five germinating walnut seeds were planted on January 3, 1969, in each 3-gallon pot. The seedlings were thinned to three per pot as soon as the first true leaves appeared. All pots were watered and maintained at or near field capacity from planting time through the start of the experimental growth period on January 30, 1969. Net height growth was determined by measuring the plants at the start and end of the experimental growth period. The plants were harvested on April 30, 1969, separated into leaf, stem, and root for drying at 70° C. in a force draft oven for 48 hours before dry weight determination. Shoot/root ratios were based on the ovendry weight of the parts.

Nutrient Determination

Nitrogen was determined on a 100 mg subsample of leaf material by micro-kjeldahl distillation. The cations and P were determined on a 500 mg subsample after wet-ashing with concentrated HNO_3 and $HC10_4$.[3] The concentrations of K, Ca, and Mg in leaf material were determined by atomic absorption. Phosphorus was determined colorimetrically by the ammonium-molybdate stannous chloride method.[4]

RESULTS AND DISCUSSION

The soil moisture treatments had the greatest effect on growth, producing highly significant differences in both height and dry weight of tops and roots (table 1). The soil and fertilizer treatments were less effective. There was no main effect of soils on height growth nor of fertilizers on root dry weight. Significant interactions occurred only where soil moisture was involved. All three treatments, soils, soil moisture, and fertilizers, had a significant effect on leaf, nutrient content (table 2).

Table 1.–Significance of treatment and interaction effects of soil texture, soil moisture, and fertilization on the growth of walnut

Source of variation	Height growth	Dry weight: Tops	Dry weight: Roots	Dry weight: Total	Shoot/root ratio
Replication	--	--	--	--	--
Treatment	xx	xx	xx	xx	xx
Soils	--	xx	x	xx	xx
Soil moisture	xx	xx	xx	xx	xx
Fertilizers	xx	xx	--	x	xx
Soils x soil moisture	--	xx	xx	xx	xx
Soil x fertilizer	--	--	--	--	xx
Soil moisture x fertilizer	--	xx	xx	xx	xx
Soils x soil moisture x fertilizer	--	xx	--	--	xx

-- Nonsignificant.
x Significant at the 5 percent level.
xx Significant at the 1 percent level.

Table 2.–Significance of treatment and interaction effects of soil texture, soil moisture, and fertilization on leaf dry weight and leaf nutient content

Source of variation	Leaf dry weight	Percent Dry Weight: N	P	K	Ca	Mg
Replication	--	--	--	--	--	--
Treatment	xx	xx	xx	xx	xx	xx
Soils	xx	xx	xx	xx	xx	x
Soil moisture	xx	xx	xx	xx	--	x
Fertilizer	xx	xx	xx	xx	xx	xx
Soils and soil mixture	xx	xx	--	--	xx	xx
Soils and fertilizer	--	xx	xx	xx	--	--
Soil moisture x fertilizer	xx	xx	xx	--	--	x
Soils x soil moisture x fertilizer	xx	xx	xx	--	xx	xx

-- Nonsignificant.
x Significant at the 5 percent level.
xx Significant at the 1 percent level.

[2] Johnson, C. M., et al. *Comparative chlorine requirements of different plant species. Plant and Soil 8: 337-355. 1957.*

[3] *Johnson, C. M., and A. Ulrich. Analytical methods for use in plant analysis. Calif. Agric. Exp. Sta. Bull.* 766, *p.* 25-78. 1959.

[4] *Chapman, H. D., and P. F. Pratt. Methods of analysis for soils, plants, and waters. Univ of Calif. Div. of Agric. Sci. Pub., Berkeley, p. 170-172. 1961.*

Height Growth

Height growth was less responsive to treatment than dry weight because much of the height growth was completed in the 30 days before the treatments started. The greatest height growth was obtained with plants grown under the field capacity soil moisture treatment plus the highest fertilizer application rate (table 3). Comparison of the main effects of the various treatments shows that most of the height growth was obtained with the first nutrient addition (table 4). For both soils and with comparable fertilizer treatments, the field capacity seedlings were significantly taller than the wilting point seedlings. No difference occurred between the soils in their effect on height growth with similar soil moisture and nutrient treatments; however, dry weight was significantly affected.

Dry Weight

Significant increases in total dry weight resulted from fertilization only in association with the field capacity treatment. The greatest yield (both dry weight and height) was obtained with the highest fertility level in sand at field capacity (table 3, fig. 1). There was no significant difference in total dry weight between the medium and high fertility levels. The lower yields from the clay soil may reflect some aeration problems in the heavier soil.

Table 4.—Individual effects and interactions of soil texture, soil moisture, and fertilization on the growth of black walnut

Treatment1/	Height growth	Dry weight: Tops	Dry weight: Roots	Dry weight: Total dry weight	Shoot/root
	Centimeters	Grams	Grams	Grams	
Soils					
Clay	4.8	12.77	26.57	39.34	0.515
Sand	4.6	17.46	33.98	51.44	.860
Water					
FC	5.8	20.81	47.00	67.81	.438
WP	3.7	9.41	13.55	22.96	.939
Clay:					
FC	5.5	16.45	37.48	53.93	.443
WP	4.2	9.08	15.66	24.74	.588
Sand:					
FC	6.0	25.17	56.51	81.68	.434
WP	3.3	9.75	11.44	21.19	1.290
Nutrients					
0	3.3	11.16	27.16	38.32	.422
1	5.5	16.02	30.56	46.58	.790
3	5.4	18.16	33.08	51.24	.852
Clay:					
0	3.2	9.68	21.48	31.17	.445
1	5.8	12.94	26.87	39.81	.530
3	5.6	15.67	31.36	47.03	.572
Sand:					
0	3.4	12.63	32.85	45.48	.400
1	5.2	19.10	34.26	53.36	1.050
3	5.3	20.63	34.82	55.45	1.130

1/ FC = field capacity; WP = wilting point; 0 = no nutrient additions; 1 = (N, P, K - 137, 38, 143 lbs/acre); 3 = (N, P, K - 411, 114, 429 lbs/acre).

Table 3.—Effects of soil texture, soil moisture, and fertilization on the growth of black walnut

Treatment Code1/	Height growth	Dry weight: Leaves2/	Dry weight: Stems	Dry weight: Total tops	Dry weight: Roots	Total dry weight	Shoot/root
	Centimeters	Grams	Grams	Grams	Grams	Grams	
Clay:							
FC-0	3.8	8.13	4.03	12.16	25.80	37.96	0.471
FC-1	6.3	11.98	4.64	16.62	39.13	55.75	.425
FC-3	6.5	14.84	5.73	20.57	47.52	68.09	.483
WP-0	2.7	5.19	2.00	7.19	17.17	24.36	.419
WP-1	5.2	7.06	2.21	9.27	14.61	23.88	.634
WP-3	4.6	8.42	2.63	11.05	15.19	26.24	.727
Sand:							
FC-0	4.0	9.93	4.84	14.77	42.40	57.17	.348
FC-1	6.3	20.08	7.92	28.00	62.32	90.32	.449
FC-3	7.6	24.91	7.83	32.74	64.80	97.54	.505
WP-0	2.7	7.69	2.81	10.50	23.30	33.80	.451
WP-1	4.2	8.01	2.21	10.22	6.20	16.42	1.650
WP-3	3.0	6.77	1.75	8.52	4.83	13.35	1.760

1/ FC = field capacity; WP = wilting point; 0 = no nutrient additions; 1 = (N, P, K - 137, 38, 143 lbs./acre); 3 = (N, P, K - 411, 114, 429 lbs./acre).

2/ No statistical analysis was made on differences among stem weights. Values covered by the same vertical line are not significantly different at the 5 percent level.

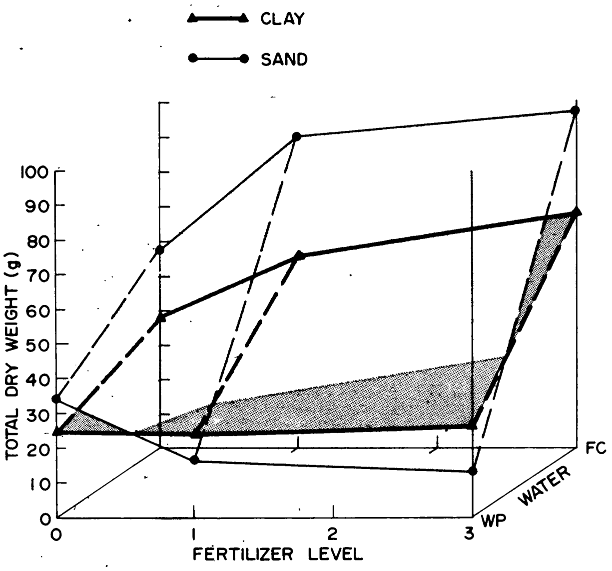

Figure 1.—The effects of soil texture, soil moisture, and fertilization on total dry weight production of black walnut.

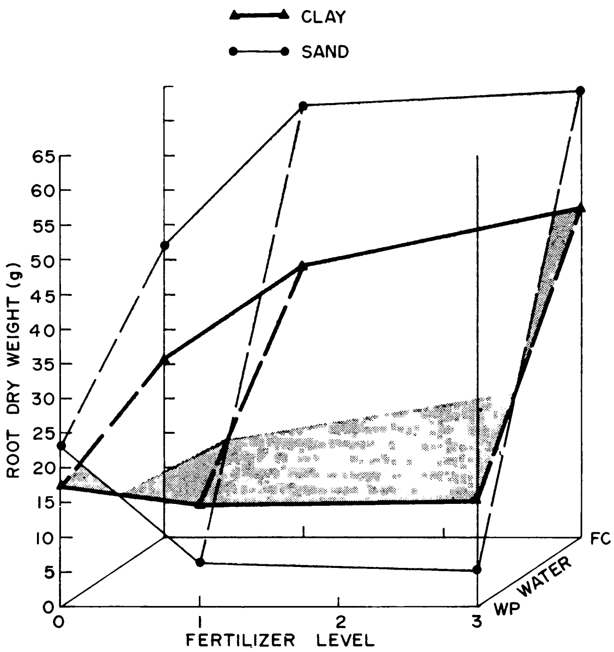

Figure 2.—The effects of soil texture, soil moisture, and fertilization on root dry weight of black walnut.

Fertilization of the sandy soil under the wilting point treatment reduced seedling growth. This was reflected in the strong fertilizer x soil moisture interactions. The decrease in total dry weight was the result of the severe reduction in root growth (fig. 2). There was no significant decrease in top growth. In this sandy soil with its relatively low exchange capacity, most of the added nutrients would remain as free ions in the soil solution. When water was removed from the system, the osmotic concentration of the soil solution could increase until the roots were damaged.

This osmotic potential can be roughly calculated by using the total molarity of the added macronutrient salts, and by assuming total ionization, no adsorption on the soil particle, and no salts already present in the soil. With these assumptions the first addition of fertilizer would provide 0.120 mole of osmotically active salt and the second addition 0.240 mole for a total of 0.360 mole. At field capacity in the clay and sand there were 4.8 and 3.7 kilograms of water respectively (total weight of soil and water at field capacity minus oven dry weight of soil). Similarly, at the wilting point the clay still retained 1.5 kilograms and the sand 0.4 kilogram of water. the osmotic pressure at field capacity and at wilting point would then be (in bars):

	Clay		*Sand*	
	FC	*WP*	*FC*	*WP*
Fertilizer 1	0.62	1.98	0.80	7.42
Fertilizer 3	1.09	5.93	2.40	22.24

In addition to these osmotic values, the soil matric potential (15 bars) would add to the stress at wilting point. The combined values of osmotic pressure and soil matric values clearly show that the total soil moisture stress was much greater in sand than in clay at the calculated wilting point. In line with this, wilting of the walnut seedlings was much more pronounced in the sandy soil than in clay as the soil moisture approached the 15 bar wilting point.

Shoot/Root Ratio

Changes in the relative weights of tops and roots can best be expressed as changes in the shoot/root ratio. Shoot/root ratios were effected little by fertilization in the well watered soil. Under the wilting point treatment, however, fertilization increased shoot/root ratios in both clay and sandy soils. For the clay soil under the wilting point treatment, fertilization increased top growth and decreased root growth. This change in dry weight distribution produced a significant increase in shoot/root ratio only between the extreme fertilizer treatments. For the sandy soil under the wilting point treatment, fertilization decreased both top and root weights; however, root weights were decreased much more than top weights resulting in the high shoot/root ratios.

Water Use Efficiency

Fertilization appears to increase the water use efficiency, assuming that evaporation from the soil surface did not change much within a particular soil moisture treatment (table 5). The amount of water used to produce a given amount of dry matter decreased in all soil moisture treatments as fertility level increased, except in the sand wilting point treatment. There fertilization resulted in a greater decrease in dry weight than in evapotranspiration, thus increasing the water use ratio.

Nutrient Uptake

NITROGEN AND PHOSPHORUS

Under moist growing conditions total dry weight increased 79 percent in clay and 71 percent in sand when the high fertility level was compared to the low fertility level (table 3).

Table 5.—Effects of soil texture, soil moisture, and fertilization on total dry weight and water use by black walnut

Treatment code 1/	Total dry weight	Evapotranspiration	Water use ratio grams H_2O/grams dry weight
	Grams	Kilograms	
Clay:			
FC-0	37.96	23.79	627
FC-1	55.75	26.71	479
FC-3	68.09	28.08	412
WP-0	24.36	13.27	545
WP-1	23.88	12.72	533
WP-3	26.24	12.76	486
Sand:			
FC-0	57.17	31.27	547
FC-1	90.32	36.93	409
FC-3	97.54	35.87	368
WP-0	33.80	15.05	445
WP-1	16.42	12.73	775
WP-3	13.35	11.93	894

1/ FC = field capacity; WP = wilting point; 0 = no nutrient additions; 1 = (N, P, K - 137, 38, 143 lbs/acre); 3 = (N, P, K - 411, 114, 429 lbs/acre).

Along with this increase in dry weight, the N concentrations in the leaves increased with the fertilizer additions in both clay and sand, while the P concentrations increased to a significant degree only in the sand (table 6). In general, for broad-leaved plants leaf concentrations of N under 2 percent and of P under 0.1 percent would indicate deficiency levels.

Table 6.—Effects of soil texture, soil moisture, and fertilization on dry weight and concentration of nitrogen, phosphorus, potassium, calcium, and magnesium of walnut leaves

Treatment 1/	Dry wt. leaves	Percent dry weight				
		N	P	K	Ca	Mg
	Grams					
Clay:						
FC-0	8.13ab 2/	1.80a	.111bc	1.01a	1.10bc	.37a
FC-1	11.98b	2.25	.101ab	1.05a	1.33c	.50b
FC-3	14.84b	2.69b	.130c	1.17a	1.40c	.50b
WP-0	5.19a	1.75a	.089ab	1.37a	.86ab	.30a
WP-1	7.06a	2.67b	.086ab	1.19a	.61a	.37a
WP-3	8.42ab	2.77b	.079a	1.30a	1.29c	.51b
Sand:						
FC-0	9.93a	1.60	.117ab	1.26a	1.32ab	.42a
FC-1	20.08	2.06a	.127bc	1.55	1.12a	.34a
FC-3	24.91	3.20b	.291	2.11b	1.41b	.42a
WP-0	7.69a	2.22a	.097a	1.24a	1.10a	.42a
WP-1	8.01a	3.51bc	.152c	1.95b	1.55b	.54
WP-3	6.77a	3.73c	.149c	2.22b	1.90	.67

1/ FC = field capacity; WP = wilting point; 0 = no nutrient additions; 1 = (N, P, K - 137, 38, 143 lbs/acre); 3 = (N, P, K - 411, 114, 429 lbs/acre).

2/ Values followed by the same subscript letter within a soil texture are not significantly different at the 5 percent level.

The N uptake did not appear to be hampered by drought conditions. A decrease in available water usually decreases growth before it affects nutrient uptake. Such growth restrictions resulted in higher leaf concentrations in the smaller plants as illustrated by N concentrations in plants grown in sand under the wilting point water regime when compared to those grown at field capacity. Phosphorus uptake, on the other hand, was considerably reduced when the plants were grown under recurring drought conditions. Both concentrations (table 6) and total contents (table 7) decreased in leaves from a WP treatment when compared to the corresponding FC treatment at the highest fertility level.

POTASSIUM, CALCIUM, AND MAGNESIUM

The concentration and total content of K, Ca, and Mg in leaves were affected by all three variables: soil type, water regimes, and nutrient

Table 7.—Effects of soil texture, soil moisture, and fertilization on dry weight and total content of nitrogen, phosphorus, potassium, calcium, and magnesium of walnut leaves

Treatment[1/]	Dry wt. leaves	N	P	K	Ca	Mg
	Grams	mg.	mg.	mg.	mg.	mg.
Clay:						
FC-0	8.13ab[2/]	144ab	9ab	85a	90ab	30ab
FC-1	11.98b	269c	12b	128abc	162cd	60cd
FC-3	14.84b	400	19	171c	208d	74d
WP-0	5.19a	91a	4a	71a	44a	16a
WP-1	7.06a	188abc	6ab	83a	68ab	25ab
WP-3	8.42ab	233bc	7ab	110ab	108bc	42bc
Sand:						
FC-0	9.93a	158a	11a	123ab	130a	41a
FC-1	20.08	415	26	310	227	68
FC-3	24.91	794	72	525	352	103
WP-0	7.69a	171ab	7a	96a	85a	32a
WP-1	8.01a	282c	12a	157b	124a	43a
WP-3	6.77a	251abc	10a	152b	128a	46a

1/ FC = field capacity; WP = wilting point; 0 = no nutrient additions; I = (N, P, K - 137, 38, 143 lbs/acre); 3 = (N, P, K - 411, 114, 429 lbs/acre).

2/ Values followed by the same subscript letter within a soil texture are not significantly different at the 5 percent level.

levels. In general, concentrations were higher in plants grown in sand than in clay (table 6). Leaf nutrient concentration also increased as the fertility levels increased, although this was not true for K in the clay and for Mg in the sand in the field capacity treatments. Where leaf nutrient concentrations did not increase with fertilization, total content did because of the greater dry weight production (table 7).

Even though the water and fertilizer treatments did affect the cation concentrations in the leaves, it is very doubtful that these changes in concentration had any effect on growth. The concentrations of mineral nutrients in a leaf can vary over a fairly wide range and have no influence on growth as long as these concentrations remain within the adequate portion of a critical nutrient level curve (that portion of the curve between the critical and toxic concentration).[5] In almost all cases, the levels in the walnut leaves appear to be within the adequate range for these cations.

SUMMARY AND CONCLUSIONS

All treatments had a significant effect on the growth and nutrient uptake of the black walnut seedlings. The dry weight of the walnut seedlings increased significantly with fertilization in both clay and sandy soils, but only under the well watered conditions. Dry weight of the seedlings grown under the wilting point treatment did not increase with fertilization. In fact, in the sandy soil with the wilting point treatment, root growth was significantly less in the fertilized treatments than in the unfertilized treatment. In this soil and under these growing conditions, even low rates of fertilization were detrimental to the growth of walnut seedlings under recurring drought conditions. This highly significant soil moisture-fertilizer interaction can be very important in nutrient studies and in field fertilization work. High rates of applied fertilizer might have no effect on growth or actually retard growth of walnut in the field if adequate water were not available. Fertilization could also increase root growth given enough soil moisture, thus tapping a greater soil volume from which additional water and nutrients could be utilized. In this study soil volume was restricted and there was no drainage from the potted soil; therefore, all of the nutrients were maintained within the root zone. Much higher rates of fertilization or more frequent applications than were used in this experiment might be necessary in the field before growth differences of this magnitude could be obtained, particularly on a sandy soil where nutrient leaching could occur.

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[5] *Smith, P. F. Mineral analysis of plant tissues. Plant Physiol. Annu. Rev. 13: 81-108. 1962.*

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- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

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