

Plant-Water Relationships and Growth of Black Walnut in a Walnut-Forage Multicropping Regime

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ABSTRACT. Eastern black walnut seedlings were planted on a 1.5 × 1.5 m spacing in the spring of 1976 and irrigated throughout the growing season. During the spring of 1977, forage plots consisting of Kentucky 31 tall fescue, orchard grass, or Kobe lespedeza measuring 1 m wide and 10.2 m long and centered on a row of trees, were established with and without irrigation. Soil-water relationships measured throughout the 1977 growing season demonstrated lower ψ_s , on the average, in irrigated than in nonirrigated plots during drought periods. Differences were attributed to the greater physiological vigor, thus greater transpiration, of forages growing under irrigated conditions. At the 45 cm depth, ψ_s dropped to a low during August of -3.0 MPa with irrigation and only -0.8 MPa without. Predawn xylem pressure potentials of walnut seedlings however, were consistently lower on forage plots without irrigation. Significant decreases in dry weights of walnut grown with forages were associated with reductions in ψ_s and increases in anthracnose infection. *FOR. SCI.* 33(1):70-80.

ADDITIONAL KEY WORDS. Irrigation, *Juglans nigra* L., tall fescue, orchard grass, Kobe lespedeza.

THE ECONOMIC AND BIOLOGICAL feasibility of black walnut (*Juglans nigra* L.) multicropping management, which involves growing walnut trees at wide spacings in association with intercrops of hay, grain, and/or grazing livestock, has been analyzed by Smith (1973), Callahan and Smith (1974), Garrett and Kurtz (1983a), and Kurtz et al. (1984). These investigators have shown that walnut multicropping is a useful alternative to conventional walnut management.

Many multicropping management regimes can be designed to accommodate the objectives of the landowner within site limitations. In the most widely applied regime in the United States, forages are grown with timber and nut producing trees. Garrett and Kurtz (1983b) have demonstrated that the yield and digestibility of cool season grasses, such as Kentucky 31 tall fescue and orchard grass can be significantly increased by growing them in the shade of intermediate-aged eastern black walnut. Therefore, multicropping management of widely spaced walnut trees with forage intercrops could be of prime importance to landowners in Missouri and throughout the natural range of this valuable species. Within the Midwest this management regime is applicable to an estimated half million ha in Missouri,

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to a similar land area in Kansas, and to over 400,000 ha in Arkansas and Oklahoma combined (Garrett and Jones 1976).

The influence of grass cover crops on tree growth is well known; however, more research on this important interaction is warranted, especially as it relates to eastern black walnut. The purpose of this study was to determine the effects of forages and irrigation on the water relations and growth of eastern black walnut seedlings during establishment.

MATERIALS AND METHODS

STUDY AREA

The study area occupied a ridge top within the Ashland Wildlife Research Area, which is located approximately 9 km east of Ashland, Missouri in southeastern Boone County (38°48'N lat., 92°12'W long., T46N, R11W). The climate is typical of the warm humid continental type (Critchfield 1966). Annual precipitation for the past 20 years has averaged 902 mm per year. The average annual temperature is 12.8°C, while the mean July temperature is 25.6°C and the mean January temperature is -2.2°C (U.S. Department Commerce 1973).

SOIL DESCRIPTION

The major soil type in the study area is an Aquic Hapludalf (Weller silt loam). In general, the soil profile is rock free and relatively deep (greater than 122 cm). The highest pH (5.1) occurs at the soil surface, it decreases to 4.4 within the A2 layer, and remains relatively constant to a depth of 122+ cm. The B horizons are characterized by clay contents ranging from 34.4% to 52.5% and low pH's (4.2 to 4.5). The highest clay content (52.5%) occurs at a depth of 24 to 45 cm. Bulk density increases from a low of 1.20 g cm⁻³ at 10 cm, to 1.60 g cm⁻³ at 20 cm, and reaches a maximum of 1.71 g cm⁻³ at 40 cm. With further increases in depth below 50 cm, bulk density remains relatively constant, averaging 1.54 g cm⁻³. Permeability is slow. A seasonal perched water table usually is present late in winter and in spring.

SITE PREPARATION AND PLANTATION ESTABLISHMENT

Prior to the spring of 1976 all vegetation (trees and shrubs) was removed and the site cleared of debris. In the spring of 1976, 1-0 barerooted black walnut seedlings were planted on a 1.5 × 1.5-m spacing. All seedlings were irrigated throughout the summer of 1976. In the spring of 1977, forage plots, 1 m wide and 10.2 m long centered on a row of trees, were established under irrigated and nonirrigated conditions. Treatments consisted of black walnut seedlings grown with tall fescue (*Festuca arundinaceae* Schreb.), orchard grass (*Dactylis glomerata* L.), Kobe lespedeza (*Lespedeza striata* Thunb. var. Kobe) and without a forage (control). Within the control plots, competing vegetation was regulated by frequent, shallow tillage to avoid walnut root damage. No attempt was made to control forage growth around walnut seedlings in the forage plots. Treatment plots, each containing seven walnut seedlings, were completely randomized and replicated five times under both irrigated and nonirrigated conditions.

Trees were irrigated from an overhead system consisting of spray stakes placed at 1 m intervals in a 1.9 cm ID polyethylene main. Frequency of irrigation was based on the average predawn xylem pressure potentials in the walnut seedlings. Whenever it approached -0.3 MPa, the irrigated plots were rewatered. Watering continued until it was estimated that predawn xylem pressure potentials would be greater than -0.10 MPa on the following morning—a requirement of approximately 2.5 cm of water.

SEASONAL WATER RELATION MEASUREMENTS

Seasonal patterns of predawn xylem pressure potential (predawn ψ_1), vapor pressure deficit (VPD), and soil water potential (ψ_s) were measured at weekly intervals from June 1 to August 18, 1977. Within a treatment, two seedlings and samples of the associated forage were selected per replication at predawn (0400 to 0500 hr) for determination of ψ_1 . Vapor pressure deficit was measured at the same time. Three replications were measured for each sampling period. Soil water potential (ψ_s) determinations were made once each sampling day.

Patterns of predawn xylem pressure potential (predawn ψ_1) were determined with a pressure chamber (Ritchie and Hinckley 1975) utilizing the precautions of Millar and Hansen (1975). Measurements were made on leaves collected by severing the rachis between the first and second pair of leaflets from the distal end of the leaf. The samples were placed in a plastic bag with moistened towels and stored in a moist container to prevent moisture loss and preserve the sample in its original condition. Determinations of ψ_1 for all samples were completed within 20 min after excision from the seedlings. Wet and dry bulb temperatures—measured with a shielded, aspirated psychrometer placed in the sampling area—were used to determine VPD. Soil moisture determinations were made with a Nuclear-Chicago neutron probe Model P-19 and a Model 2800A scaler. Soil moisture access tubes were distributed throughout the study area between the treatment plots. Soil moisture measurements were made at 15 cm intervals to a depth of 75 cm. Calibration curves developed for the site by Chambers (1976) were used to convert neutron probe readings to soil moisture tensions.

PLANT MEASUREMENTS

Anthracnose (*Gnomonia leptostyla* [Fr.] Ces. and deNot) infection was assessed on July 8 and August 30. The degree of infection was rated subjectively on a scale of 0 to 3 with a rating of 0 representing no damage and 3 severe damage.

A 100% leaf area sample of each walnut seedling was made during the second week of September. Leaf area was computed using an area-to-weight regression formula developed prior to sampling. All leaves were removed from each seedling and oven-dried at 70°C for 48 hr. Dry weight determinations were made and converted to area estimates using the equation:

$$\text{Leaf Area} = 6.576 + 154.115 (\text{dry wt. of walnut leaves}); \quad R^2 = 0.99.$$

Density of forage roots by 5 cm increments to a depth of 30 cm was estimated at the same time using a cylindrical sampler. Extracted cores measured 30 cm in length and 10 cm in diameter. Three cores were extracted for each forage treatment on both the irrigated and nonirrigated plots. The cores were sectioned at 5 cm intervals, and the soil washed from the roots. The volume of forage roots by soil depth was determined by placing the roots in a 100 ml graduated cylinder and measuring water displacement to the nearest ml.

Following the collection of foliage and forage root cores, ten walnut seedlings from each forage treatment and control (irrigated and nonirrigated) were lifted with a hydraulic tree spade (1 m in diameter) and the soil carefully removed. Roots and shoots of each selected seedling were oven-dried at 70°C for two days and dry weights determined.

DATA ANALYSIS

The study was established as a split plot design. All data within whole plots (irrigation vs. no irrigation) were subjected to analysis of variance and differences among treatment means (subplots) were compared with the least significant differences (LSD) test at the ($P \leq 0.05$) level.

RESULTS AND DISCUSSION

Rainfall was uniform and above average throughout the growing season of 1977, and prolonged periods of drought did not occur. Some moisture stress was observed, however, and irrigation began on June 1 and continued through August.

SOIL WATER POTENTIAL

Soil water potential (ψ_s) at 15 cm in the irrigated and nonirrigated control plots generally remained above -0.03 MPa while it decreased at intermediate depths (Figure 1a and b). At 45 cm, ψ_s reached -0.40 MPa in the irrigated plots and -0.53 MPa in the nonirrigated. Irrigation, above average precipitation, the absence of competing vegetation, and poor internal drainage resulted in sufficient soil moisture in the upper 30 cm to support good plant growth. Soil factors restricting percolation included fine texture, weak structure, high clay contents, and concomitant high bulk densities in the subsoil (Figure 2). Soil moisture depletion patterns suggest that black walnut seedlings on the irrigated control plots were drawing much of their water from the 45 cm depth with some also coming from 60 cm. Walnut on the nonirrigated control plots seemingly relied less on the moisture available at 60 cm and absorbed much of their water from depths of 30 and 45 cm (Figure 1b). These data correlate well with observations made during preliminary root mapping, which showed that the majority of walnut roots were located between the depths of 20 and 40 cm (Figure 2).

On the irrigated and nonirrigated walnut-forage plots, ψ_s at 15 cm generally remained above -0.10 MPa until mid July–August and then decreased to ap-

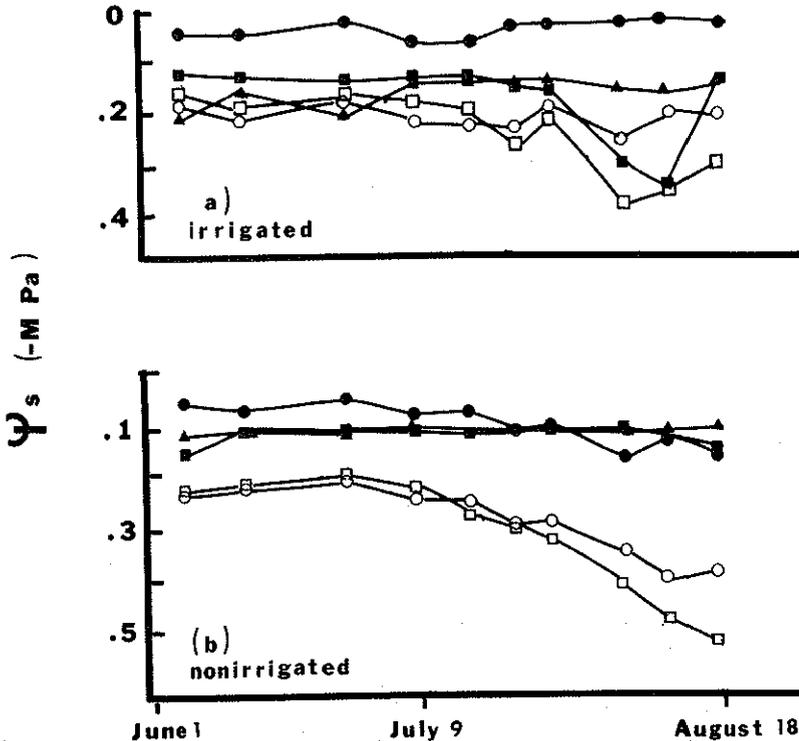


FIGURE 1. Seasonal patterns of soil water potential (ψ_s) on irrigated (a) and nonirrigated (b) control (cultivated) walnut plots at 15 cm (●), 30 cm (○), 45 cm (□), 60 cm (■), and 75 cm (▲).

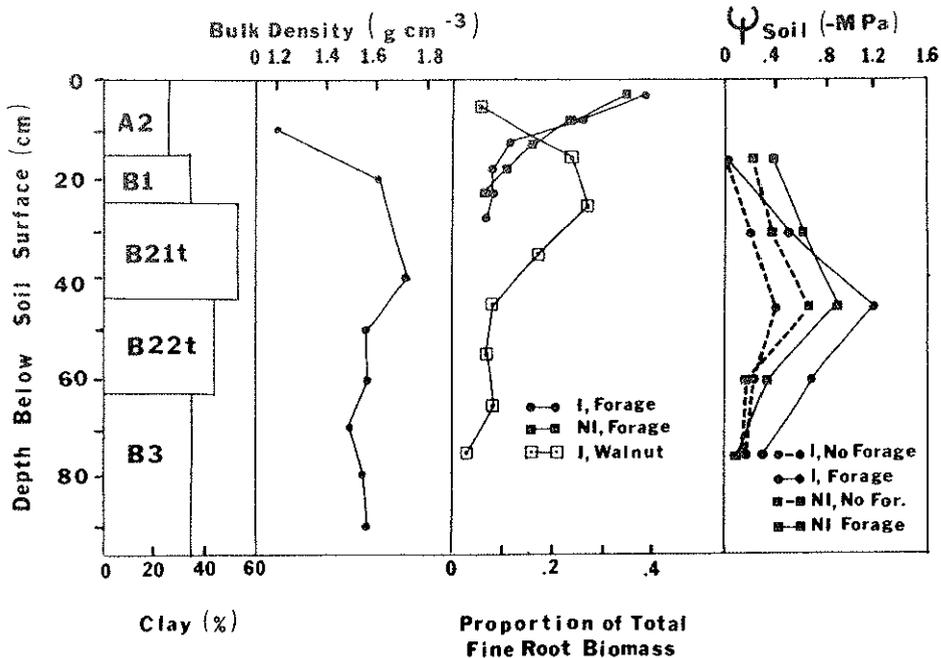


FIGURE 2. Relationships between soil horizons, bulk density, soil water potential during the driest period, and root distribution of forages and eastern black walnut seedlings.

proximately -0.31 MPa (Figure 3a and b). The largest reductions in ψ_s during the growing season occurred at the intermediate depths. At 45 cm, ψ_s dropped as low as -3.00 MPa in the irrigated forage plots while in the nonirrigated it reached -0.85 MPa. A similar, though less pronounced, pattern of decreasing ψ_s between irrigated and nonirrigated forage plots was observed at 60 and 75 cm.

As forages depleted soil water supplies in the upper soil, competition for water between forage and walnut and subsequent reductions in ψ_s became greater at lower depths. Similar patterns in water extraction by forages have been reported by Doss et al. (1962).

During the mid and late part of the growing season, when atmospheric evaporative demand was high, transpirational losses of soil water were seemingly greater on the irrigated forage plots than on the nonirrigated at 30, 45, 60, and 75 cm. Irrigation had maintained the physiological activity of these forages while increasing the amount of forage canopy, and hence the transpirational surface. This increase in transpirational surface was substantiated by early forage production estimates made on June 16. Irrigated orchard grass and fescue had twice as much forage yield ($1,010$ and $1,055$ kg ha^{-1}) as the same forages grown under nonirrigated conditions (427 and 449 kg ha^{-1}). Kobe lespedeza produced the most forage. Irrigated Kobe averaged $1,998$ kg ha^{-1} while nonirrigated Kobe yielded $1,549$ kg ha^{-1} . During mid-to-late July, days were typically hot and rainless. All nonirrigated forages experienced substantial vegetative dieback. Under these more dormant conditions, loss of soil moisture through transpiration was reduced, resulting in slightly higher ψ_s on the nonirrigated than on the irrigated forage plots. Johns and Lazenby (1973), measuring water use of both dryland and irrigated monoculture swards of white clover, perennial ryegrass, tall fescue, and phalaris, observed a similar relationship—water use of dryland swards was 32% less than that of irrigated swards.

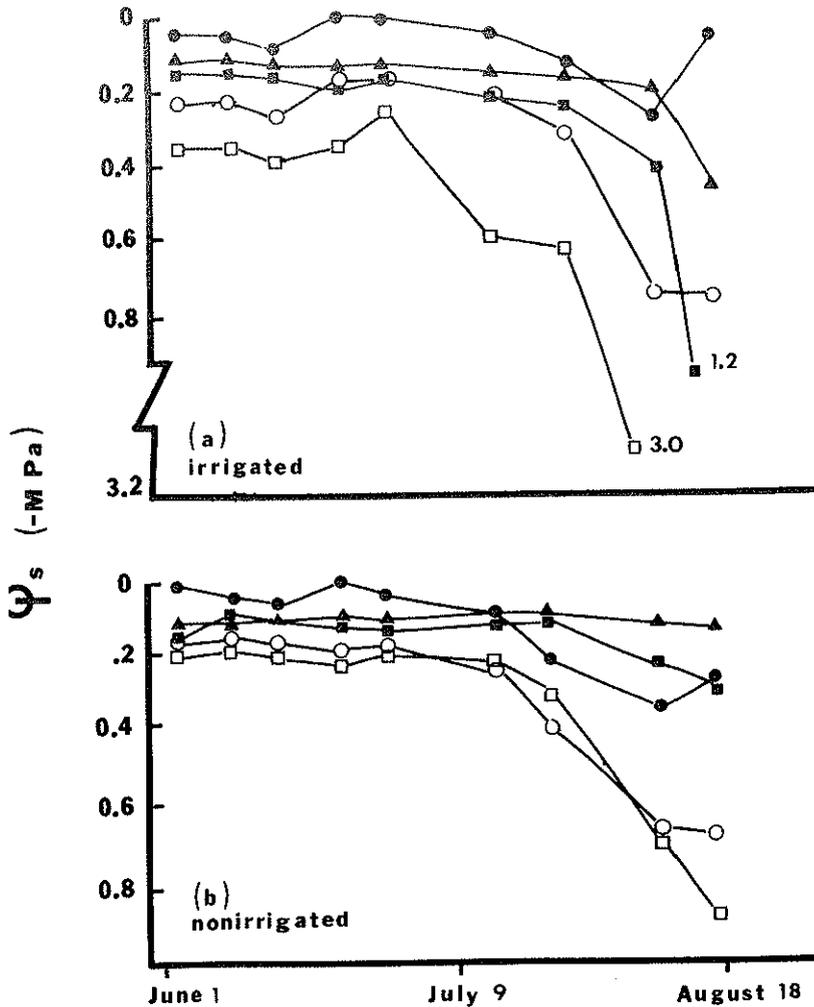


FIGURE 3. Seasonal patterns of soil water potential (ψ_s) on irrigated (a) and nonirrigated (b) forage-walnut plots at 15 cm (●), 30 cm (○), 45 cm (□), 60 cm (■), and 75 cm (▲).

For practical irrigation purposes, the upper 30 cm of soil is the most important zone early in a multicropping program of walnut and forages since it contains most of the roots (Figure 2). If irrigation could maintain sufficiently high ψ_s in the upper 30 cm throughout the season to meet forage water use, then competition for water between walnut and forages at depths below 30 cm would be minimized. More water would be available in the lower soil zones for absorption by walnut. The amount of irrigation water that actually entered and percolated through the profile in this study, however, was restricted by soil properties, and substantial runoff occurred. While irrigation was sufficient to maintain an actively transpiring forage canopy, the amount of water penetrating the soil was apparently inadequate to meet the total transpirational needs of the forages. Thus, the forages relied more on soil water reserves at depths below 15 cm and increased the competition with black walnut.

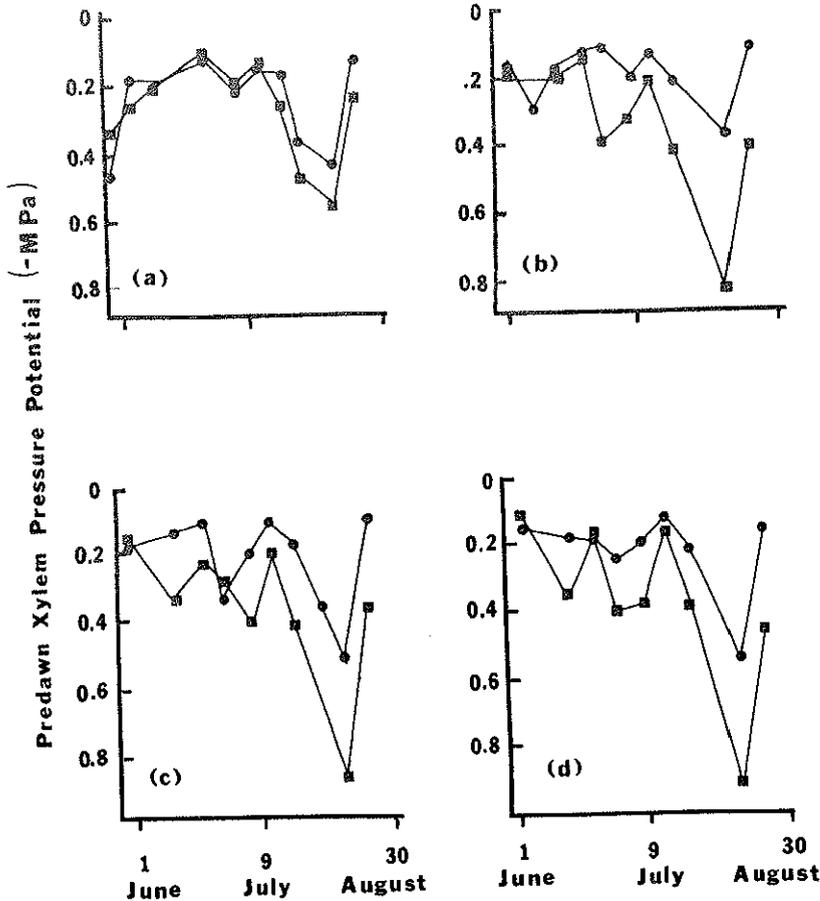


FIGURE 4. Seasonal patterns of walnut predawn xylem pressure potential in irrigated (●), and non-irrigated (■), treatments where walnut seedlings were grown alone (a), with Kobe lespedeza (b), tall fescue (c) or orchard grass (d).

SEASONAL PATTERNS OF PREDAWN XYLEM PRESSURE POTENTIAL

During 1977, predawn xylem pressure potential (predawn ψ_1) for irrigated and nonirrigated control walnuts were similar and generally above -0.20 MPa until mid-July (Figure 4a). Before July 15, ψ_s for all depths in both control treatments was also generally greater than -0.20 to -0.30 MPa (Figure 1). Traces of precipitation occurred frequently during early June with sufficient rain falling in late June to maintain high soil moisture and predawn ψ_1 levels.

During late July and early August, rainfall became less frequent at a time when atmospheric evaporative demand was high. Consequently, ψ_s , especially at the 30, 45, and 60 cm depths, declined to minimum values due to walnut transpiration. Predawn ψ_1 became less in nonirrigated than in irrigated control trees during this period. The maximum difference in minimum predawn ψ_1 between walnut in the control treatments was 0.12 MPa (Table 1). Differences between average predawn ψ_1 for irrigated and nonirrigated control trees, however, were not significant (Table 1). Water deficits in the control walnuts were low throughout the summer because soil moisture supply was adequate and competing vegetation controlled.

TABLE 1. Average seasonal (June 1–August 30) and minimum base xylem pressure potential (predawn Ψ_i) in irrigated (I) and nonirrigated (NI) black walnut in control and three forage treatments. The same values are also given for the forage species.

Species	Pre-dawn Ψ_i P (MPa)	Control		Kobe lespedeza		Tall fescue		Orchard grass								
		I	NI	I	NI	I	NI	I	NI							
		Black walnut	Ave -0.25 ^{a1}	-0.27 ^a	-0.19 ^a	-0.36 ^a	-0.22 ^a	-0.38 ^a	-0.23 ^a	-0.38 ^a	Min -0.44 ^a	-0.56 ^a	-0.37 ^a	-0.83 ^b	-0.52 ^a	-0.88 ^b
Kobe lespedeza	Ave —	—	-0.18 ^a	-0.72 ^b	—	—	—	—	Min —	—	-0.34 ^a	-1.96 ^b	—	—	—	—
Tall fescue	Ave —	—	—	—	-0.17 ^a	-0.63 ^b	—	—	Min —	—	—	—	-0.37 ^a	-1.76 ^b	—	—
Orchard grass	Ave —	—	—	—	—	—	—	-0.18 ^a	-0.63 ^b	Min —	—	—	—	-0.46 ^a	-2.00 ^b	—

¹ Irrigated and nonirrigated treatment values within a plant species followed by the same letter are not significantly different ($P \leq 0.05$).

Predawn ψ_i of irrigated and nonirrigated walnut grown with Kobe lespedeza, tall fescue, or orchard grass responded in a similar manner in all cases with predawn ψ_i reaching more negative values in nonirrigated than in irrigated plots (Figure 4b, c, and d). There were no significant differences in average predawn ψ_i of black walnut (range -0.19 to -0.38 MPa) between any of the irrigated or nonirrigated forage treatments (Table 1). There were significant differences in the minimum predawn ψ_i noted (range 0.37 to 0.91 MPa), however, suggesting that under conditions of prolonged drought, averages of predawn ψ_i would likely be significantly different.

Predawn ψ_i for the irrigated forages were consistently higher than those observed on nonirrigated plots. Minimum predawn ψ_i for irrigated and nonirrigated forages ranged from -0.34 to -2.00 MPa (Table 1). Because forage roots were more abundant in upper soil depths (Figure 2), predawn ψ_i reached more negative values for nonirrigated forages than for the deeper rooted walnuts.

WALNUT GROWTH RESPONSES

Root and shoot growth of control walnut seedlings was apparently inhibited by the higher soil moisture conditions created through irrigation as dry weights were less for irrigated than for nonirrigated plants. Pham et al. (1977) reported decreases in fine root percentages and number of roots < 1 mm diameter in 35-yr-old black walnut as potential soil water availability increased from the top to the bottom of a second bench slope. Similar results were cited by Keyes and Grier (1981) for Douglas-fir (*Pseudotsuga menziesii*).

Soil water potentials in the zones of maximum root concentrations varied greatly between cultivated walnuts and those grown with forages in this study (Figures 1 and 3). At 30 cm, ψ_s never dropped below -0.4 MPa on the control plots (irrigated or nonirrigated—Figure 1) but decreased to an average of -0.68 under the non-irrigated forage treatments (Figure 3). Competition with forages significantly affected root growth of black walnut and emphasizes the importance of weed control in walnut management. While not explored in this study, allelopathy may also have contributed to differences in root development observed. Walters and Gil-

TABLE 2. Average root and shoot dry weight, leaf area, and anthracnose ratings for black walnut seedlings either clean-cultivated or grown with a forage crop under irrigated and nonirrigated conditions.

Treatment	Root dry weight (g)	Shoot dry weight (g)	Leaf area (cm ²)	Anthracnose rating	
				July 8	Aug. 20
Irrigated walnuts with:					
Cultivation	85.4 ^{a1}	32.8 ^a	2,504 ^a	0	0.7 ²
Tall fescue	59.9 ^a	14.1 ^b	487 ^b	1.2	2.4
Orchard grass	48.4 ^a	15.1 ^b	282 ^b	1.0	2.3
Kobe lespedeza	41.0 ^a	13.6 ^b	371 ^b	0.8	1.9
Nonirrigated walnuts with:					
Cultivation	113.8 ^a	38.7 ^a	2,846 ^a	0	0.8
Tall fescue	31.2 ^b	13.7 ^b	572 ^b	1.3	2.1
Orchard grass	22.5 ^b	11.9 ^b	616 ^b	1.2	2.3
Kobe lespedeza	41.2 ^b	14.0 ^b	586 ^b	1.2	2.1

¹ Values within irrigated or nonirrigated treatments followed by the same letter for a growth measurement are not significantly different ($P \leq 0.05$).

² The degree of anthracnose infection was rated on a subjective basis from 0 to 3. A rating of 0 represented no infection while that of 3 represented severe infection. Intermediate ratings of 1 and 2 represented low and moderate amounts of infection, respectively.

more (1976) for example, reported significant decreases in the growth of sweetgum watered with a Kentucky 31 tall fescue leachate.

Even in the absence of competing vegetation, walnut root growth on control plots was not extensive in this study. Biswell (1935) reported an average rooting depth of 68 cm and a lateral spread of 30 to 61 cm for 1-yr-old walnut seedlings. Holch (1931) reported that roots of 1-yr-old walnut trees grew vertically to a depth of 96 cm with a lateral spread of 86 cm. Root systems of 2-yr-old seedlings in this study had a maximum depth of 75 cm with a width of 48 cm. Soil characteristics that could have limited root growth included high clay concentrations, high bulk densities, and poor internal drainage (Figure 2). The below-average root and top growth observed in this study emphasizes the importance of selecting deep, well-drained soils for black walnut. Moreover, the growth problems observed with irrigated control plants accent the difficulty of overcoming some site problems through cultural treatments. It is noted, however, that walnuts grown with forages benefited from irrigation. Root dry weights of irrigated plants grown with tall fescue and orchard grass were twice as great as for similar seedlings grown without irrigation. The average predawn ψ_1 of irrigated walnuts was 0.13 MPa higher than for nonirrigated, which may account for some of the difference observed. Although a strong correlation was not found, the relationship may have been confounded by a secondary effect of irrigation on leaf surface area.

In general, leaf areas for seedlings in the various treatments followed a pattern similar to that observed for root and shoot development. Control walnuts produced comparable amounts of foliage regardless of soil moisture conditions although a 12% reduction did result from irrigation. The growth of forages with the walnuts resulted in significant decreases in tree leaf area from that observed in the controls (Table 2). Irrigated control seedlings yielded an average of 2,504 cm² leaf surface area/seedling while nonirrigated plants produced 2,846 cm². No significant differences were found in leaf areas between seedlings grown with the various forages; however, irrigated walnuts grown with a forage produced an average of only 380 cm² compared to 591 cm² for nonirrigated plants. Carpenter

(1974) reported leaf areas for 2-yr-old walnuts ranging from 771 to 2,489 cm²—substantially above those observed for 2-yr-old walnut (2 years in the field) grown with forages in this study but comparable to the control seedlings. While Heiligmann and Schneider (1974) reported that total leaf area of walnut was significantly reduced by low soil moisture in their work, this would not seem to explain differences observed in our study. Predawn xylem pressure potentials of walnuts were high through mid-July regardless of treatment (Figure 4). Since walnut leaves emerge and expand almost entirely by mid-July, it would appear that soil water availability was adequate to provide maximum leaf development. Moreover, in this study, the second flush was complete by July 18.

Anthracnose infection may account for some of the differences observed in leaf area and plant dry weights. An initial survey of anthracnose damage made on July 8 showed an average infection of 1.1 (Table 2) for all treatments. Infection was rated subjectively from 0 to 3, with 0 representing no infection and 3 severe infection. Despite control efforts (spraying of bentholate), infection on walnuts grown with a forage increased faster than on control seedlings and reached serious proportions (average rate of 2.2) by August 30. Controls averaged only 0.8. While the infection rating was similar for both irrigated and nonirrigated walnuts grown with a forage crop, defoliation was greater under irrigated conditions presumably due to a more moist environment. Although leaves dropped as a result of anthracnose infection were collected daily, dried, weighed, and added to those removed at final harvest, some foliage may have been inadvertently lost. The higher anthracnose infection on trees grown with grasses, especially in combination with irrigation, indicates a potential problem early in any management program incorporating forages or irrigation. Furthermore, restricted growth patterns of irrigated control seedlings emphasize the effects that soils with compacted layers can have on walnut development. This is especially important in view of the abundance of walnut being planted on previously farmed lands that contain compacted zones.

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