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Yield, maturation, and forage quality of alfalfa in a black walnut alley-cropping practice

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Abstract There is interest in producing alfalfa as an alley crop because alfalfa (*Medicago sativa* L.) is the most profitable hay crop in the USA. Field experiments were conducted near Stockton, MO in 2003 and 2004. Treatments consisted of alfalfa grown in open plots and in plots that were alley cropped between 20-year-old black walnut trees (*Juglans nigra* L.) planted in rows 24.4- and 12.2-m apart. Alfalfa was sampled for three harvest cycles each year. In the alley-cropping plots, samples were taken beneath the canopy (2.5 m from the tree row) and in the center of the alleys. Data were taken on dry-matter yield, maturity, and forage quality. At all harvest dates over both years, yields from beneath the canopy of both alleys and the narrow alley centers were less than yields from the wide alley centers and open plots. Yield from the wide alley centers was similar to that in open plots in every harvest but the final harvest of 2004. Transects across the plots indicated that yields increased linearly from the tree row to the center of both alleys. Alfalfa tended to mature faster in the open and wide alley centers compared to beneath the canopy of both alleys and the narrow alley centers. Forage quality differences were inconsistent across treatments. Alfalfa yield was significantly reduced and maturity was delayed by the narrow 12.2 m tree spacing, but yield was not reduced in the centers of the wider 24.4 m alleyways.

Keywords *Juglans nigra* · *Medicago sativa* · Shade tolerance

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Introduction

Alfalfa is noted for its superior forage quality and yield potential (Marten et al. 1988). It is the most important forage species in the USA and is one of only a few forage crops grown in every state (Barnes and Sheaffer 1995). Because alfalfa can be readily sold as a hay crop, there is interest in growing alfalfa in an alley-cropping practice. Also, integrating trees and forage crops can increase diversity compared to traditional monoculture (Holloway and Stork 1991; Stamps and Linit 1998) and legumes can provide nitrogen rich organic matter to improve soil fertility for the tree crop (Bugg et al. 1991). However, little information is available on how alfalfa responds to black walnut alley cropping environments.

Eastern black walnut, (*Juglans nigra,* L.) is a hardwood species native to the eastern USA. It is a premium hardwood used for fine furniture, flooring, architectural woodwork, veneer, and is a nut producing tree. The nuts are used as food additives and the hard shell or pericarp is used as an abrasive.

Alley cropping with nut trees is the most common type of agroforestry in the Midwestern United States, and black walnut is one of the most common trees used for the practice. Alley cropping has the potential to provide numerous benefits to both the grower and the environment, but the lack of information on the interaction of the trees with various crops has hampered its acceptance.

Competition for light, moisture, and nutrients, and possibly allelopathy can reduce intercrop growth and yield in agroforestry systems. Shade created by trees modifies the environment in the alleys and can affect the yield of forage crops (Pearson 1983; Watson et al. 1984). Peri et al. (2001) found that alfalfa dry matter production decreased by 36% under a stand of 10–11-year-old radiata pine (*Pinus radiata* D. Don) trees compared to the open. Burner and Brauer (2003) found that tall fescue (*Festuca arundinacea* Schreb.) herbage yield decreased with decreased spacing between loblolly pine (*Pinus taeda* L.) trees. Lin et al. (1999) compared the growth of alfalfa in pots under 100% sunlight to alfalfa grown under 50% and 20% sunlight simulated by shade cloth. They found a 24% and 56% reduction in growth for 50% and 20% light treatments, respectively. Moisture competition was shown to be more important than competition for light and nutrients, or allelopathy, in reducing intercropped corn yield in an 11-year-old black walnut alley cropping system (Jose et al. 2000a). Because alfalfa growth is reduced when moisture is below −0.3 MPa (Douglas 1986), moisture competition is likely to affect intercropped alfalfa and reduce yields. Nutrient competition occurs in alley-cropping systems, but Jose et al. (2000b) suggest that it is dependent on soil moisture and the level of competition present. Further, they found that competition was primarily for existing mineralized N and not fertilizer N. As alfalfa is an N-fixing legume, competition for N would likely be minimal; however, alfalfa requires large amounts of Ca and K (Frame et al. 1998) and competition for these elements might be considerable. Levels of juglone that have been shown to be allelopathic in laboratory settings have been found in black walnut plantings so allelopathy may also reduce alfalfa growth. However, levels of juglone decline rapidly with distance from the tree (Jose and Gillespie 1998; Ponder and Tadros 1985) so allelopathy likely has little influence on the intercrop species more than a few meters from the tree row.

The primary factor affecting forage quality at harvest time is maturity (Collins and Fritz 2003). Forage quality declines as plants age. Mean stage by count (MSC) quantifies the stage of development in alfalfa and is an established method for predicting forage quality (Mueller and Fick 1989). Shade may affect maturity, and thus forage quality, in an alfalfa alley crop practice (Neidermann and McGraw, unpubl. data). Moisture stress, if not severe, also delays maturity and increases alfalfa forage quality (Frame et al. 1998).

Some researchers have reported that shade may increase nitrogen concentration, thus increasing crude protein concentration. Lin et al. (2001) found that paniculated tick trefoil (*Desmodium paniculatum* L.) under artificial shade showed increased crude protein (CP) compared to 100% light. Some researchers reported no effect on nitrogen concentration under varying levels of light. Peri et al. (2001) found that CP content of alfalfa was not affected by shading of 10–11-year-old radiata pine trees. Lin et al. (2001) found that CP content in alfalfa was not different under 50% and 80% artificial shade compared to 100% light. Research is mixed on how light effects neutral and acid detergent fiber (NDF and ADF) content of forages. Increased fiber contents lead to reduced forage digestibility and intake. Lin et al. (2001) found that ADF and NDF increased in alfalfa under 50% and 80% artificial shade compared to 100% light. In contrast, NDF did not differ and ADF decreased in striate lespedeza (*Kummerowia striata* (Thumb.) Schindler 'Kobe'), paniculated tick trefoil, and *Desmodium canescens L.* compared to 100% light. Johnson et al. (2002) found that NDF decreased in rhizoma peanut (*Arachis glabrata* Benth.) with increasing light.

Our objective was to determine the effect of black walnut alley cropping at wide and narrow alley spacings on field grown alfalfa forage yield, on forage maturity as measured by mean stage by count and on forage quality as measured by crude protein, neutral detergent fiber and acid detergent fiber. To do this, alfalfa yield, maturity, and quality from samples beneath the tree-row canopy and in the center of alleys was compared to that in open plots. Alfalfa yield was also sampled every meter from the tree row to the alley centers to define the distance at which interference and/or competition from black walnut diminishes.

Materials and methods

Field experiments were conducted at the Hammons Products Sho-Neff Black Walnut Plantation (37°50′ N, 93°50′ W) near Stockton, MO, USA. The soil was a Cliquot-Bolivar complex (fine-loamy, mixed, active, thermic Ultic Hapludalf) with a pH of 6.1 as extracted with a calcium chloride solution. Immediately after each alfalfa harvest, 213 kg/ha of 0–60–60 N–P–K and 11 kg/ha of boron was applied. Alfalfa variety WL 322GZ was seeded at 22.5 kg ha^{-1} in August of 2002 in plots between 20-year-old black walnut trees planted in rows 24.4- and 12.2-m apart and in an open area. The 24.4-m tree row spacing will be referred to as wide alleys and 12.2-m tree row spacing as narrow alleys. Height of the black walnut trees was measured with a Haga altimeter and averaged 9.5 m. Trees within rows were 3-m apart, with resulting tree densities of 264 trees/ha for 12.2-m alleys and 132 trees/ha for 24.4-m alleys. Diameter at breast height was measured on two trees per plot and averaged 22 cm.

Plots were sampled for three harvest cycles in 2003 and 2004. Alfalfa herbage was cut 5 cm above the soil surface from two 1.0-m^2 areas within each plot on May 21, June 24, and August 7 in 2003 and May 19, June 23 and July 22 in 2004. One sample was taken beneath the tree canopy (25 m from the tree row) and one in the center of the alley. In the open plots, two samples were taken from each plot. Herbage samples were dried in a forced-air oven at 55°C for 48 h and weighed to determine dry matter yield. Sub-samples from DM samples were taken for forage quality. Dried herbage samples were ground in a Wiley mill to pass a 2-mm screen then in an UDY cyclone sample mill (UDY Corp., Ft. Collins, CO) to pass a 1-mm screen. Samples were stored in sterile sampling bags at −40°C until assayed for CP, ADF and NDF. At each harvest date, maturity was determined by taking approximately 50 alfalfa stems from each sample and separating them into ten morphological stages as described by Kalu and Fick (1981). These ten stages fit into four developmental categories: vegetative, flower bud development, flowering, and seed production. Mean stage by count was calculated using the following equation:

$$\mathrm{MSC} = \sum (S \times N)/C*,$$

where S = stage, N = number of shoots in stage S, and C = the total number of shoots in the sample.

Crude protein, NDF and ADF concentrations were determined by Custom Laboratories (Golden City, MO). NDF and ADF were determined using methods described by Goering and Van Soest (1970). Crude protein was calculated as N × 6.25 (AOAC International 1995); N was determined by Kjeldahl method.

Yield transects were taken at three harvest dates (6 Sept 2003, 13 Oct 2003, and 24 May 2004). Alfalfa herbage was sampled every 1 m from the tree row to the center of the wide and narrow alleys, starting 1.5 m into the alley. Samples were cut 5 cm above the soil surface from a 1 × 0.5 m area at each sampling location. Dry matter yield was determined by the same methods previously described.

The data were analyzed with a one-way analysis of variance (ANOVA) followed by Fisher's least significant difference tests (LSD) to separate means (PROC GLM, SAS Institute 2001; Snedecor and Cochran 1989). Means were considered statistically different at the 0.05 probability level according to LSD.

Results and discussion

Yields from both years from the wide alley centers were statistically similar to open plots in all but the final harvest date in August 2004 (Tables 1 and 2). Reasons for the yield difference in the final harvest are unclear. At all harvest dates over both years, yields beneath the tree canopy of both alleys and the narrow alley centers were less than yields from the wide alley centers and open plots. In 2003, yields declined as the season progressed for all treatments but was most apparent at the last harvest probably due to low soil moisture. Rainfall totaled only 13.3 cm during the final two harvest periods compared to 23.8 cm during the final two harvests in 2004. At the final harvest in 2003, yields beneath the tree canopy and the narrow alley centers were reduced, relative to the two previous harvests, to a greater degree than yields from the open plots or wide alley centers (Table 1). Yields were reduced an

Table 1 Dry-matter yield and mean stage by count (MSC) of alfalfa grown for three harvest cycles in open plots and under trees spaced 12.2- and 24.4-m apart near Stockton, MO, USA in 2003

Treatment	Location[a]	21 May		24 June		7 August	
		Yield (kg ha^{-1})	MSC	Yield (kg ha^{-1})	MSC	Yield (kg ha^{-1})	MSC
Open		4,017a[b]	3.1a	3,834a	3.4a	949a	2.9a
24.4-m	Center	4,308a	3.0ab	3,337a	3.5a	813a	2.0ab
24.4-m	Canopy	2,824b	2.5b	1,945b	3.3a	315b	1.0bc
12.2-m	Center	3,064b	2.3b	2,162b	3.0a	336b	0.8bc
12.2-m	Canopy	2,492b	2.3b	1,904b	3.0a	255b	0.5c

[a] Center refers to the center of the alleys and canopy refers to beneath the canopy of the trees

[b] Values within a column followed by the same letter are not different at the 0.05 probability level according to LSD

average of 78% in the open and wide alley centers compared to the average of the first and second harvests in 2003. Meanwhile, beneath the canopies of both alley widths and center of the narrow alleys yield was reduced an average of 88% compared to the first and second harvests in 2003. Yields beneath the canopy of both alleys and the narrow alley centers were similar for all harvests in both years except for the June 2004 harvest (Table 2).

Yield data from transects across the alleys indicated that alfalfa yield increased linearly with distance from the tree row in the narrow and wide alleys ($Y = 2.96X + 15.88$, $r^2 = 0.95$ and $Y = 3.98X + 22.04$, $r^2 = 0.99$, respectively) (Fig. 1). The slope and intercept of each line is consistent with findings that the wide alleys produced more herbage than the narrow alleys.

Alfalfa yield was reduced beneath the canopy and in the center of the narrow alleys relative to that grown in open plots. We expected alfalfa to yield poorly beneath the tree canopy and several factors likely contributed to the low yield including competition for moisture, light, nutrients, and possibly allelopathy. Moisture competition reduces crop yields near black walnut (Jose et al. 2000a) and likely contributed to alfalfa yield losses here, particularly, in mid to late summer when precipitation was often lacking. Shade also likely reduced yields beneath the canopy and near the tree rows. In shade, beneath similar-sized, open-grown black walnut, PAR (photosynthetically active radiation) can be reduced below 350 μmol m^{-2} s^{-1} during mid day (Houx, unpubl. data). This is considerably less than alfalfa's light saturation point of 1,200–1,400 μmol m^{-2} s^{-1} (Sheehy and Popple 1981) and may have contributed to lower yields beneath the canopy. Nutrient competition, particularly for K and Ca may have also affected growth near the trees. However, competition for N is not considered as alfalfa is a N-fixing legume. Beneath the canopy and near the tree rows, allelopathy may have also affected yield. Juglone can reach levels in field settings that have been shown to be allelopathic under laboratory conditions (Jose and Gillespie 1998) and alfalfa is considered susceptible to juglone (Macdaniel and Pinnow 1976).

Alfalfa yield increased linearly from beneath the canopy to the center of both alleys. In the wide alleys, yields increased up to a distance of 11.5 m from the tree row. This result was surprising as we expected the trees to have a limited influence beyond a distance of 6–8 m from the tree row. Competition for moisture, light, and nutrients may have reduced growth in the alleys. Jose et al. (2000a) showed that soil moisture was the most important factor in reducing corn yield in a black walnut alleycropping system. In their study, black walnut affected soil moisture up to 4.3 m from the tree row (the center of the alley). The trees in their study were nearly half the age and DBH as those in our study so it is plausible that trees in our study were affecting soil moisture beyond a distance of 4.3 m from the tree row. Further, black walnut trees of similar size or age have been shown to have lateral roots extending up to 16 m from the tree (Stone and Kalisz 1991) so it is possible that trees could be competing with the alfalfa for moisture and nutrients across both the narrow and wide alleys. In north-south oriented alleys, the amount and intensity of photosynthetically active radiation is typically greater in the center of alleys than near the tree row (Gillespie et al. 2000b; Settle and Houx unpubl. data). Light

Table 2 Dry-matter yield and mean stage by count (MSC) of alfalfa grown for three harvest cycles in open plots and under trees spaced 12.2- and 24.4-m apart near Stockton, MO, USA in 2004

Treatment	Location[a]	19 May		23 June		22 July	
		Yield (kg ha^{-1})	MSC	Yield (kg ha^{-1})	MSC	Yield (kg ha^{-1})	MSC
Open		2,809a[b]	2.1a	3,538a	3.9ab	2,876a	3.3a
24.4-m	Center	2,998a	2.0ab	3,500a	4.3a	2,470b	3.3a
24.4-m	Canopy	1,268b	2.0ab	1,524c	3.0c	1,102c	2.5b
12.2-m	Center	1,753b	2.0ab	2,290b	3.3bc	1,067c	2.3b
12.2-m	Canopy	875b	1.8b	1,343c	2.8c	878c	2.0b

[a] Center refers to the center of the alleys and Canopy refers to beneath the canopy of the trees

[b] Values within a column followed by the same letter are not different at the 0.05 probability level according to LSD

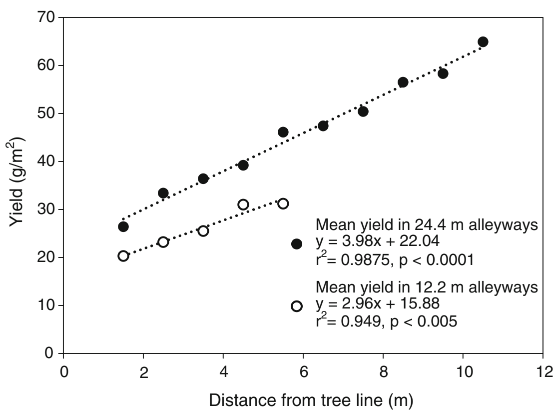

Fig. 1 Mean alfalfa yield for three sampling dates (6 Sept 2003, 13 Oct 2003, 24 May 2004) for the 12.2 m and 24.4 m wide alleyways

differences across alleys had little effect on corn yield in a similar study (Gillespie et al. 2000). As a C4 species, corn should be less tolerant to shading than alfalfa so yield reductions in the alleys may be more attributable to moisture and nutrient competition. Black walnut allelopathy may have reduced yield near the tree rows. However, Jose and Gillespie (1998) showed that exractable juglone declined rapidly with distance from the tree row so it is likely that allelopathy had a limited affect near the center of the alleys. Alfalfa yield in the center of the wide alleys was not reduced relative to that grown in the open suggesting that this distance (12.2 m) may be the limit for competition in this alley-cropping system.

Alfalfa forage maturity as measured by mean stage by count was similar between the open plots and the wide alley centers for each harvest both years (Tables 1 and 2). Compared to the open plots, maturity of alfalfa harvested from beneath the canopy of the wide alleys and the narrow alley centers was always less than in the open plots; however, the differences were not always significant. Alfalfa maturity beneath the canopy of the narrow alleys was always significantly less than that in the open except at the June harvest of 2003. Reduced light has been shown to delay maturity in alfalfa (Niedermann and McGraw 2004) and likely affected maturity in this study.

Few differences were found in CP, ADF, or NDF concentrations between alfalfa grown in the open and alfalfa grown as an alley crop with black walnut. No significant differences were found in forage quality between alfalfa in the open and alfalfa grown in the center of the wide alleys (Tables 3 and 4). Fiber concentrations, as measured by ADF and NDF, only differed significantly among treatments three times—all in 2003. In all three cases the plots closest to the trees had less fiber than the plots further from the tree. However, fiber was always similar between the open and narrow alley centers. Crude protein concentrations differed among treatments in three of the six harvests (June 2003, August 2003, and August 2004); however, the differences were not consistent. Alfalfa in the open plots and wide alley centers always had similar CP concentrations and alfalfa beneath the canopy of both alleys and the narrow alley centers always were similar in CP as well.

The primary factor affecting forage quality at harvest time is maturity (Collins and Fritz 2003). Less mature alfalfa should have more CP and less fiber than more mature alfalfa. Since alfalfa harvested from beneath the canopy of the wide alleys and the narrow alley centers was always less mature than in the open plots, we would expect forage quality to be consistently better; however, our data does not show a consistent increase in quality.

Table 3 Crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) of alfalfa grown for three harvest cycles in open plots and under trees spaced 12.2- and 24.4-m apart near Stockton, MO, USA in 2003

Treatment	Location[a]	21 May			24 June			7 August		
		CP	ADF	NDF	CP	ADF	NDF	CP	ADF	NDF
Open		18.7a[b]	31.1ab	42.8a	21.0ab	30.4a	38.7a	18.1b	30.5a	38.4ab
24.4-m	Center	16.9a	32.4a	44.0a	22.2a	28.2ab	36.4a	18.0b	33.4a	42.8a
24.4-m	Canopy	16.9a	31.7ab	43.4a	19.1c	28.6ab	38.6a	21.6a	28.3a	35.7b
12.2-m	Center	18.6a	29.5b	40.8a	20.7abc	29.9ab	39.0a	20.6ab	30.0a	39.1ab
12.2-m	Canopy	18.1a	30.1ab	42.7a	19.7bc	27.1b	36.4a	21.2a	31.2a	39.3ab

[a] Center refers to the center of the alleys and Canopy refers to beneath the canopy of the trees

[b] Values within a column followed by the same letter are not different at the 0.05 probability level according to LSD

Table 4 Crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) of alfalfa grown for three harvest cycles in open plots and under trees spaced 12.2- and 24.4-m apart near Stockton, MO, USA in 2004

Treatment	Location[a]	19 May			23 June			22 July		
		CP	ADF	NDF	CP	ADF	NDF	CP	ADF	NDF
Open		21.7a[b]	26.1a	36.7a	21.7a	28.4a	36.8a	21.0a	22.6a	30.0a
24.4-m	Center	21.4a	27.9a	38.0a	21.8a	29.1a	37.3a	22.2a	26.0a	34.5a
24.4-m	Canopy	19.7a	26.6a	36.3a	21.4a	30.5a	39.5a	19.2b	24.4a	33.7a
12.2-m	Center	21.9a	27.5a	37.7a	21.4a	29.5a	38.5a	17.8b	25.8a	34.4a
12.2-m	Canopy	19.9a	28.2a	38.3a	22.5a	27.6a	36.7a	19.9ab	23.2a	31.7a

[a] Center refers to the center of the alleys and Canopy refers to beneath the canopy of the trees

[b] Values within a column followed by the same letter are not different at the 0.05 probability level according to LSD

Summary and conclusions

Alley cropping alfalfa with black walnut primarily affected alfalfa yield and maturity. Yield increased linearly from beneath the tree canopy to the center of the wide alleys suggesting that black walnut can influence alfalfa growth up to a distance of 11.5 m from the tree row. Maturity and yield were delayed beneath the black walnut canopy and suggests that light is limiting alfalfa; however, other factors like moisture and nutrient competition, or possibly allelopathy would also likely affect alfalfa yields near the tree rows. Few differences were found in CP, ADF, and NDF concentrations between the alley-cropped and open-grown alfalfa. Because alfalfa yield in the center of the wide alleys was not reduced compared to the open, this distance (12.2 m) may be the limit for competition in this alley-cropping system. Growth was reduced in the center of narrow alleys and growth increased linearly to the center of wide alleys suggesting that at this stage of tree growth alfalfa would likely not be a compatible intercrop in these alley widths. However, cultural management such as lateral root pruning or branch pruning may decrease competition from the trees and increase yields. Further studies are needed to assess these cultural management factors and to assess alfalfa as an intercrop in younger black walnut alleycropping systems where tree competition would be less.

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