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A review of suitable companion crops for black walnut

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Abstract Black walnut (*Juglans nigra* L.) is a temperate tree grown for nuts and wood, but it is allelopathic to certain plants and animals. We compiled reports of valuable black walnut companion crops which may be grown in the short term (<15 years after planting walnut trees), medium term (15–30 years), and long term (>30 years). There are many black walnut companion cropping systems for the short and medium term, but there are few for the long term. Companion crops for black walnut serve multiple functions, including nitrogen fixation, added yields, the development of straight walnut stems, and added protection from forest pests such as deer. Black walnut polyculture is a viable alternative worthy of further development and implementation.

Keywords Allelopathy · *Juglans nigra* · Juglone · Permaculture · Polyculture

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Introduction

Black walnut (*Juglans nigra* L.) has a mixed reputation. On the one hand, it is a valuable tree crop with beautiful heartwood and delicious nuts. On the other hand, it is known to produce allelopathic chemicals that inhibit the growth of other plants (Willis 2000). There have been dozens of studies in recent years on black walnut multi-cropping systems, but the dominant narrative has remained roughly the same: black walnut is a long term tree crop, allelopathic in general, which at best can be expected to permit the co-existence of one additional farm yield chosen from a small pool of tolerant species. This paper aims to shift that narrative, to one of multiple potential yields, which can recover stand establishment costs and add revenue streams up to the day of the timber harvest.

Black walnut is bred for various products (Reid et al. 2004). The maroon-black heartwood is the most valuable black walnut yield, which is made into furniture, veneer, and gunstocks. This lucrative commodity was once raised as a "retirement crop": farmers would sell an old black walnut stand to fund their retirement. The nuts of the tree are edible, and black walnut has been described as "the most dependable nut plant for Illinois" (Meador et al. 1986). Nut crops can be produced by young trees, but yields are influenced by site, tree variety, and management practices. The market for black walnuts is not as well developed as that for carpathian walnuts

(*J. regia* L.). Black walnut sap may be processed into a sweet syrup comparable to maple syrup (Matta et al. 2005), but the sap is more dilute in black walnuts. Black walnut syrup is novel, but trivial in economic terms. The most valuable commercial yield of the black walnut, its heartwood, is not ready for harvest until decades after stand establishment. If black walnut production is going to produce value in the short term, additional crop species are required, especially species that can produce economic value during the first 20 years after establishment of the black walnut stand. The major barrier to black walnut polyculture is its reputation as an allelopath.

Black walnut and other members of the family Juglandaceae have long been known to produce an allelopathic compound known as "juglone" which inhibits the growth of several other species of plant (Davis 1928; Willis 2000). Roots, leaves, and hulls contain large quantities of harmless hydrojuglone, which may be oxidized to juglone (Segura-Aguilar et al. 1992), then transferred to neighboring plants primarily as a root exudate in the rhizosphere of the black walnut trees (Bertin et al. 2003). In susceptible plants, juglone interferes with respiration and photosynthesis (Hejl et al. 1993). Affected plants turn brown, wilt, and die. Most vegetable crops are vulnerable to juglone toxicity (Crist and Sherf 1973), as are some fruit tree species and all members of the plant family Ericaceae (Brooks 1951). In the animal kingdom black walnut hulls are responsible for triggering lamnitis, an often fatal hoof condition in horses (Thomsen et al. 2000) which may harm fish (Radix et al. 1992) and repel ants and flies (Walker 1990). Common midwest crops which are susceptible to the presence of black walnut include corn and soybeans (Jose and Gillespie 1998b; Hejl and Koster 2004), wheat and alfalfa (Bertin et al. 2003).

What types of crops can be raised in black walnut plantations in the midwestern United States? Lists of "compatible" and "incompatible" species are available in extension publications (Crist and Sherf 1973; Funt and Martin 1993; Baughman and Vogt 2002), but they often contradict each other (Gordon 1981; Anonymous 1998), and are not clearly supported by scientific literature. Still, this is the most wide-ranging information available on the subject, and it has been generated by experienced and professional growers. Our detailed assessment of extension literature and of the published scientific literature shows that there is a veritable "guild" of species which will live with the walnut forest in all stages of its development. In this paper, we briefly introduce the buildup of juglone during the establishment of black walnut plantings, and describe reports of added yields of food and wood, nitrogen fixation, and tree protection which may be attained in the short and medium term. In doing so, we show that a black walnut polyculture is not only possible, but economically viable as well.

Spatial and temporal buildup of juglone

Several factors influence the accumulation of juglone in a growing area, including rhizosphere interactions, uptake by soil organisms, adsorption of juglone to soil particles, and movement in the soil solution. Living black walnut trees exude juglone into the rhizosphere (Bertin et al. 2003), which likely explains reports that allelopathy can continue after walnut tree removal, especially if the stumps are not killed (Piedrahita 1984). A species of *Pseudomonas* has been identified that can metabolize juglone (Schmidt 1988) potentially providing a juglone sink, but it is unlikely that these bacteria prevent plant exposure to the juglone. Juglone in solution may also be adsorbed to soil particles or organic matter (Willis 2000). Soil moisture regime seems to augment the effects of juglone exposure. A study with white pine (*Pinus strobus* L.) suggests that poorly drained soils may exacerbate the effects of juglone toxicity: pines growing near black walnut on a well drained soil grew tall, while pines growing near black walnut on a poorly drained soil died (Fisher 1978). Though juglone accumulation is dynamic, any area planted with black walnuts may potentially show symptoms of allelopathy.

How many years after planting black walnut do toxic juglone effects appear? Various estimates include 12–25 years (Rietveld 1981; Rink 1985), 15–20 years (Dawson et al. 1981); or 12–15 years (Beineke 1985). A high-intensity planting of black walnut (5.5 m × 5.5 m) interplanted with juglone-sensitive Alder trees (*Alnus glutinosa* [L.] Gaertn.) resulted in toxic effects linked to juglone after only 5 years (Bohanek and Groninger 2005). Plantations designed for nut harvesting and other agroforestry practices such as pasture may be spaced closely within rows and widely between rows. For instance, 6′ × 30′ spacing gives 242 trees per acre while creating a space between rows in which juglone accumulates less quickly (Baughman and Vogt 2002). Given the caveat that different spacings will produce different rates of juglone accumulation in the area between the walnut trees, we have designated three periods of juglone accumulation at 15 year intervals (see Table 1).

Short term: multicropping during stand establishment

Immediately after black walnut seedlings are planted, the area between the rows may be planted with juglone-sensitive crops, but after 10–15 years the juglone and shade will put constraints on what may be grown. In the first few years of growth, Black Walnut will grow a deep taproot and put on 12″–18″ of top growth (3′–4′ under intensive culture) annually (Rink 1985). Full sun is available for roughly 5–7 years, and it would not be unlikely to see juglone affecting sensitive species by the tenth year. Our research suggests that it is prudent to treat the 10–15 year old black walnut stand as a transition period to a more shady and allelopathic medium term. Studies on short term companion plants for black walnut have therefore included juglone-tolerant trees and livestock, pasture and forage, and all sorts of annual produce for the period just after the trees are planted.

Typical midwest annual crops may be planted between widely spaced rows of black walnut seedlings. Good walnut sites may also be good soybean and wheat sites, though shade has been reported to affect these crops after 7 years, even with the rows spaced 40 feet apart (Burde 1989). Corn has been raised between rows of black walnut, but it has also been demonstrated that after 10 years corn productivity is reduced by something other than the aboveground competition for light, probably juglone (Jose and Gillespie 1996). The concentration of juglone in the soil, varies as a function of the distance from the rows. In one study, juglone decreased in concentration by 80% at a distance of 4.25 m from a row of 10 year old black walnut trees (Jose and Gillespie 1998a). When juglone was added to hydroponically grown corn and soy in the same concentration found in the alley cropping study, there were significant inhibitory effects on plant growth (Jose and Gillespie 1998b). Later work isolated the mechanisms by which juglone disrupts corn and soy growth (Hejl and Koster 2004). Annual crops may be viable between rows of black walnut for up to 5–10 years, but probably not longer.

An interplanting of trees may help produce straight black walnut trunks while adding a short to medium term yield of non-walnut timber. European Black Alder (*Alnus glutinosa* L.), was planted simultaneously with Black Walnut as a nitrogen fixing nurse crop with an added yield of harvestable pole wood, in an Illinois-based study (Bohanek and Groninger 2005). The Alder trees would be completely killed by the level of juglone released by a 20-year-old Black Walnut, so wood harvests must commence between 5 years and 15 years after establishment. The authors claim that the alder sale could pay for the cost of establishing the Black Walnut stand if the alders are harvested in well-timed thinnings between 4 years and 19 years after stand establishment (Bohanek and Groninger 2005).

There is evidence that short term planting of livestock forage or pasture in black walnut plantations do not restrict livestock growth, and that livestock manures may benefit the adolescent walnut trees. A pine-walnut plantation with annual ryegrass (*Lolium multiflorum* Lam.) and cereal rye (*Secale cereale* L.) between the rows as heifer pasture, produced approximately 80% of the forage produced in a control plot without trees, but beef heifer average daily weight gain was equal for both treatments

Table 1 Three phases of black walnut stand development

Period Yields	Timeframe	Allelopathy	Black Walnut
Short term	0–15 years	None to low	–
Medium term	15–30 years	Low to high	Nuts
Long term	30< years	High	Wood, nuts, sap, shade

(Kallenbach et al. 2006). This suggests that beef producers likely would not sacrifice livestock production when they graze animals under 6–7 year old pine and walnut trees compared to open pasture. After chicken manure was applied as a fertilizer to a young (3-year-old) Black Walnut plantation in Missouri, total height and leaf nitrogen concentrations increased during the summer, suggesting that poultry manure is valuable as a fertilizer during establishment of young walnut plantations (Ponder et al. 2005). In addition to being a suitable environment for poultry, a modular or free-range chicken pasture might also benefit young black walnut trees.

Young black walnut plantations have been used to grow forage for farm animals to eat off site, and shade (not juglone) seems to be the main issue limiting productivity. Fescue (*Festuca arundinacea* Schreb.) grown in 7–8 year old black walnut stands produced significantly more forage in medium density stands (7.3 m between rows) versus low or high density stands (14.6 m and 1.8 m between rows, respectively) (Buergler et al. 2005). A comparison of overall forage yields in fescue fields planted with black walnut and honey locust (*Gleditisia triacanthos* L.) showed that forage production decreased more dramatically under high density Honey Locust than under high density Black Walnut (Buergler et al. 2005).

There are a handful of vegetable crops that are reportedly tolerant of juglone, including onions (*Allium cepa* L.) (MacDaniels and Pinnow 1976), parsnips (*Pastinaca sativa* L.) (MacDaniels 1974), Jerusalem artichokes (*Helianthus tuberosum* L.) (Ross 1996), sugar beet (*Beta vulgaris* L.) (Piedrahita 1984) and certain species of bean (*Phaseolus* spp.) (MacDaniels and Pinnow 1976). The yields of these crops might not be harmed by juglone, but the increasingly shady conditions cast by the canopy will make these annuals less viable in the medium term.

Managing a black walnut stand in the short term, there are at least a few years when the juglone effect is negligible, before soil juglone concentrations increase while ground-level sunlight availability decreases. Sun-loving juglone-intolerant crops may be leveraged so long as they are not required to return top yields into the medium term. For this reason, annual crops may be the smartest way to leverage some quick revenue from the young black walnut stand. All temperate climate plants are potential candidates for interplanting with black walnut in the first few years, and a clever application of this fact could set the stage for a second phase of yields during the medium term.

Medium term: farming amongst mature trees

There are several medium term crops that can provide valuable functions such as nitrogen fixation, and add yields such as wood 15–30 years after stand establishment (see Table 2). Species living in the black walnut stand during this period must be tolerant of juglone and shade. Even with widely spaced rows, shade is considerable after 15 years. The woody species listed below might best be planted simultaneously with the black walnuts, so that they grow up with the black walnut and develop straight stems, while receiving enough sunlight to produce yields such as fruit or bolewood. Animal species such as heifers and hens benefit from partial shade available in the adolescent walnut stand. Most medium term species could also be raised in the short term, but the available reports focus on older stands.

Several soft fruit species are compatible with black walnut, and can make good use of the transitional medium term phase of the walnut stand. A 1951 paper summarized 12 years of surveying plant species found growing within and around black walnut trees in five US states (Brooks 1951). This is the most methodical survey of naturally occurring black walnut compatible plants to date. Brooks reported that black raspberry (*Rubus occidentalis* L.) grew under black walnut canopy whereas blackberry (*Rubus fruticosus* L.) only grew outside the crown area; currants (*Ribes* spp.), elderberry (*Sambucus canadensis* L.), and wild grapes (*Vitis* spp.) were common under black walnut canopy, whereas blueberry (*Vaccinium* spp.) and other ericaceous plants were never observed near black walnut (Brooks 1951). Mulberry (*Morus* spp.) and pawpaw (*Asimina triloba* [L.] Dunal) trees were also found to be tolerant of black walnut whereas apples (*Malus* spp.) and pears (*Pyrus* spp.) were not (Schneiderhan 1927; Brooks 1951). One grower has claimed multiple sightings of American Persimmons (*Diospyros virginiana* L.) growing and producing fruit under black walnut canopy (Gordon 1981).

Table 2 Short term, medium term, and long term yields which are possible in the presence of black walnut trees

Species	Yield	Source
Short term: <15 years		
Juglone-intolerant field crops	Grain, produce, forage	Burde 1989; Jose and Gillespie 1996.
Alfalfa (*Medicago sativa*)	Forage	Brooks 1951.
Cereal rye (*Secale cereale*)	Forage	Kallenbach et al. 2006.
Fescue (*Festuca arundinacea*)	Forage	Buergler et al. 2005.
Ryegrass (*Lolium multiflorum*)	Forage	Kallenbach et al. 2006.
Jerusalem artichokes (*Helianthus tuberosum*)	Vegetable	Ross 1996.
Lima bean (*Phaseolus lunatus*)	Vegetable	MacDaniels and Pinnow 1976.
Onion (*Allium cepa*)	Vegetable	MacDaniels and Pinnow 1976.
Parsnips (*Pastinaca sativa*)	Vegetable	MacDaniels and Pinnow 1976.
Sugar beet (*Beta vulgaris*)	Vegetable	Piedrahita 1984.
Wax bean (*Phaseolus vulgaris*)	Vegetable	MacDaniels and Pinnow 1976.
Cattle (*Bos taurus* L.)	Meat, dairy	Kallenbach et al. 2006.
Chicken (Gallus gallus)	Meat, eggs, manure	Ponder et al. 2005.
Medium Term: 15–30 years		
Fescue (*Festuca arundinacea*)	Forage	Funt and Martin 1993.
Kentucky Bluegrass (*Poa pratensis*)	Forage	Orton and Jenny 1948; Brooks 1951 Piedrahita 1984; Funt and Martin 1993.
Red Clover (*Trifolium pratense*)	Forage, N-fixer	Boes 1986.
Timothy (*Phleum pratense*)	Forage	MacDaniels and Pinnow 1976; Boes 1986.
White clover (*Trifolium repens*)	Forage, N-fixer	Piedrahita 1984; Boes 1986.
Black Raspberry (*Rubus occidentalis*)	Fruit	Brooks 1951; MacDaniels and Pinnow 1976; Piedrahita 1984; De Scisciolo et al. 1990; Fuchs 1995.
Currant (*Ribes* spp.)	Fruit	Brooks 1951; Anonymous 1998.
Elderberry (*Sambucus canadensis*)	Fruit	Brooks 1951; Anonymous 1998
Mulberry (*Morus* spp.)	Fruit	Brooks 1951; Mollison 1988.
Pawpaw (*Asimina triloba*)	Fruit	Brooks 1951; Anonymous 1998.
Persimmon (*Diospyros virginiana*)	Fruit	Gordon 1981.
Autumn olive (*Elaeagnus umbellata*)	N-fixer	Ponder et al. 1980.
Black locust (*Robinia pseudoacacia*)	N-fixer, wood	Ponder et al. 1980.
European alder (*Alnus glutinosa*)	N-fixer, wood	Bohanek and Groninger 2005.
Russian olive (*Elaeagnus angustifolia*)	N-fixer	Burde 1989.
Black walnut (*Juglans nigra*)	Nuts	
Eastern white pine (*Pinus strobus*)	Wood	Fisher 1978; Burde 1989.
Red oak (*Quercus rubra*)	Wood	Burde 1989.
Sugar maple (*Acer saccharum*)	Wood	Burde 1989.
White ash (*Fraxinus americana*)	Wood	Burde 1989.
Long term: >30 years		
Bamboo (*Phyllostachys* spp.)	Wood, edible shoots	(author's observation)
Black walnut (*Juglans nigra*)	Wood, nuts, sap	
Ginseng (*Panax quinquefolium*)	Medicinal roots	Apsley 2004; Carroll 2004.
Mushroom logs	Mushrooms	

There are several nurse crops recommended for black walnut growers which are planted at time of stand establishment, then harvested or killed in the medium term. Autumn olive (*Elaeagnus umbellata* Thunb.), Russian olive (*Elaeagnus angustifolia* L.), European alder (*Alnus glutinosa* (L.) Gaertn.), and black locust (*Robinia pseudoacacia* L.) are nitrogen fixers, and eastern white pine (*Pinus strobus* L.), red oak (*Quercus rubra* L.), white ash (*Fraxinus americana* L.), and sugar maple (*Acer saccharum* Marsh.) are grown for their wood (Burde 1989). An Illinois study found that autumn olive and black locust both improve black walnut growth, which is attributed to their role as nitrogen fixers (Ponder et al. 1980). There are also reports that autumn olive may reduce leaf spot and anthracnose (Kessler 1988) because associated microarthropods consume the leaf litter carrying the disease (Kessler 1990). Autumn olive is shorter than black walnut; it prevents deer from damaging walnut trunks without over topping and competing for sunlight. Black locust quickly grows tall, potentially competing with black walnut trees via shading. Black locust can be cropped for bolewood and the resultant nitrogen release in the root zone could benefit adolescent Walnut trees, whereas autumn olive would die off due to shade in the medium term and release N without providing a wood crop. The nurse crops grown for wood help develop straight walnut stems, and in the case of European alder, can over-top the walnut trees before dying of juglone toxicity (Rietveld et al. 1983). A similar story is apparently the case for the fast-growing, but juglone-intolerant eastern white pine (Fisher 1978) and sugar maple (De Scisciolo et al. 1990).

Growing forage for livestock may be one of the most profitable uses of walnut plantation land in the medium term. It is common in extension bulletins to report that grasses such as Kentucky blue grass (*Poa pratensis* L.) and tall fescue (*Festuca arundinacea* Schreb.) grow well under black walnut (Funt and Martin 1993). A comparison of the heights of black walnut trees in the lower midwest found that 26 year-old black walnut trees growing with Kentucky blue grass had a site index 5 m greater than trees growing within tall fescue fields (Ares and Brauer 2004). There is also potential for leguminous forage production: red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.) appear to be compatible with black walnut trees (Brooks 1951; Boes 1986), though alfalfa (*Medicago sativa* L.) is not (MacDaniels and Pinnow 1976). It may benefit black walnut trees to grow Kentucky blue grass and clover in the earlier part of the medium term, before the shade becomes too dense to permit profitable growth.

Long term yields

Reports of valuable companion crops for mature walnut stands are scarce. A walnut plantation is shady and allelopathic after 30 years. A well-developed stand of walnut trees will have long straight trunks and a closed canopy 20–30 feet above the ground. Viable understory flora must tolerate shade and juglone. The late leafing-out date of black walnut, combined with the early leaf-drop that may be triggered by anthracnose diseases, can create sunny periods in spring and fall (Woeste and Beineke 2001), which suggests that spring ephemerals and late-ripening fruits might play a useful role in the long term. Other productive species might find the summer shade useful, such as mushrooms or livestock, though the scarcity of literature suggest that most growers are going to be prepared to sell the wood once the black walnut stand has reached maturity.

There is scarce scientific literature on the subject of full-shade cropping systems under black walnut. The presence of black walnut has been called "a good indicator...of productive sites" for growing American ginseng (*Panax quinquefolium* L.) (Apsley 2004; Carroll 2004). Shiitake (*Lentinula edodes* Berk.) and Oyster (*Pleurotus* spp.) mushroom operations require shady environments such as the mature walnut grove can provide, but there are no specific reports of culinary mushroom interactions with juglone. Forest yields such as mushroom logs and pawpaw (*Asimina triloba*) may require shade to stay moist in the summer, but pawpaw is more productive when mature trees receive full sun. Similarly, temperate bamboo (*Phyllostachys* sp.) has been observed growing under the high crown of mature black walnuts in Urbana, IL, though it seems to grow tallest in the sunny edges. *Phyllostachys* can provide trellis material, edible shoots, and even a "wood" crop in sunny positions, but its slow growth and sun requirements may disqualify it from long term walnut polyculture. There is no mention of bamboo in the black walnut literature.

Livestock operations may make use of the walnut stand as a source of shade for their animals, but there is no known benefit to the walnut trees. The application of poultry litter to a 35 year old stand of black walnuts in Missouri failed to produce significant differences in nut yield or diameter growth (Ponder et al. 2005). Furthermore, the livestock will require food that can only be grown in sunny locations. The shortage of literature on long-term black walnut polyculture suggests that the value of a mature black walnut stand is enough for most growers without additional yields.

Discussion

A forester with the singular objective of producing black walnut wood as fast as possible will find that intensively planting trees in protective plastic tubes, applying herbicide to understory vegetation, and applying chemical fertilizers in the rows during stand establishment is the quickest route (Bendfeldt et al. 2001; Ponder and Jones 2001; Cutter et al. 2004). But the highest intensity route also carries the highest input cost, by ruling out opportunities for multi-cropping or providing comparable functions with flora such as nitrogen fixing nurse crops.

Black walnut could be re-cast as an ecological resource if its beneficial interactions were emphasized as often as its detrimental interactions. Black walnut's allelopathic chemical juglone is lethal to some popular flora, but the remainder of the plant kingdom may effectively receive a selective advantage due reduced competition when grown with black walnut. Additionally, black walnut is not likely to attract insect pests, as the leaves have been observed to be amongst the least popular for forest insect pests (Shields et al. 2003), which holds consistent with their reputation as folk insect repellant (Walker 1990). Though black walnut trees can inhibit some plants from growing, it has never been demonstrated to "ruin the soil" as is often rumored, and to the contrary it appears that soil processes such as nitrification occur unfettered in the soil with juglone (Thevathasan et al. 1999). Black walnut wood chip mulch is often suspected to be antagonistic to plant growth, but a recent study found black walnut chips to be the least inhibitory of six species of wood chips tested for allelochemical response (Rathinasabapathi et al. 2005).

Black walnut is not universally detrimental to other cropping systems. Soil type and moisture regime have been implicated in differential juglone toxicity levels detected in soils (Fisher 1978; Zitzer and Dawson 1989). For some species black walnut may function as a friend rather than foe due to reduced competition with susceptible species (Brooks 1951). Earthworms may be scarce under black walnut (MacDaniels and Pinnow 1976) but arthropods may be more abundant and diverse (Summers and Lussenhop 1976). Elevated soil pH (Brooks 1951) and soil organic matter levels under black walnut have been attributed to the retardation of decay organisms (Summers and Lussenhop 1976). It could be that some plants take up juglone from the soil (Thijs et al. 1994) and could thus function as "buffer" species for juglone-intolerant crops.

This assessment suggests the need to de-stigmatize juglone and recast it as a resource in need of management. Just like shade, low pH soil, or a dry moisture regime, juglone will favor certain species and disadvantage others. The prospect of growing black walnut polycultures in the short and medium term, merits further research. The logic of short-term gains is a major argument against tree crops in the midwest, and the potential for multiple yields in an ecosystem mimicking polyculture could become its counterargument. Research in the long term (>30 years) is especially sparse in terms of polycultural alternatives, likely owing to the practice of fastest-possible returns: selling the black walnut stand once sufficient stem diameter is achieved. For black walnuts to become an investment that people protect as carefully as their retirement funds, a new generation of research and production based on compatibility and diversity may be required.

The negative reputation of walnut allelopathy dates back to ancient Greece (Willis 2000). The discovery of juglone in the 20th century, and its identification as a causal agent in black walnut allelopathy, helped frame an era of research in which the toxic effects were put in focus. Since 1980, there have been several papers reporting successful polyculture production methods with black walnut, including mixed stands, alley-cropping and silvopasture. There now exists a lengthy list of companion species that may be grown with black walnut stands, adding value to the system by making use of its unique conditions. Though there is not a single agroforestry system for black walnut growing, a collection of species compatible with black walnut gives good reason to rethink the reputation of this important tree, and ask whether the juglone could not be re-cast as a resource. Our findings suggest that it can, and that there may be multiple benefits for growers who choose to do so.

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