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Article

Previous Land Use and Invasive Species Impacts on Long-term Afforestation Success

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Abstract: The conversion of agricultural lands to forests has increased worldwide over the past few decades for multiple reasons including increasing forest connectivity and wildlife habitat. However, previous land cover and competing vegetation often impede afforestation. We established 219 plots in 29 *Quercus* plantations on four previous land cover types (LCT): Clover, Soybeans, Woody Brush, and Herbaceous Weeds. Plantations were located in Illinois, USA and were sampled 15–18 years after planting. Sampling data for all trees (planted and volunteer) included species, diameter, and vine presence on the main bole of the tree. Free-to-grow status was recorded for all *Quercus* species and estimated cover of two invasive species, *Elaeagnus umbellata* and *Lonicera japonica*, was documented on each plot. There was a strong relationship between total tree density and invasive species cover across all sites. Stocking success was lower and *E. umbellata* cover was higher on Woody Brush sites compared to Clover and Soybean cover types. Additionally, significantly more free-to-grow *Quercus* saplings occurred in Clover and Soybean cover types compared to the Woody Brush sites. The results indicate that previous land cover plays a critical role in forest afforestation. Furthermore, while historically, volunteer tree species were thought to be detrimental to the development of planted species these results suggest that with the increasing prevalence of invasive species worldwide the role of volunteer species in afforestation should be reconsidered and silvicultural protocols adjusted accordingly.

Keywords: *Quercus*; Autumn olive; Japanese honeysuckle; Forest restoration

1. Introduction

The conversion of land from agriculture fields and pastures back to forest cover has become a common management objective on marginal and/or environmentally sensitive agricultural lands worldwide [1–3]. These lands, often supporting the growth of valuable timber species and host to a number of ecosystem services, were cleared in order to accommodate vast agricultural expansion throughout much of the globe over the past two centuries. For example, in the eastern United States, conversion to agricultural land peaked at approximately 100 million hectares in the early 1900s and occurred primarily on lands dominated by forests/woodlands [4]. This rapid conversion created large amounts of land that proved to be marginal for agricultural crop production and subject to abandonment when crop markets were weak or the land became less productive [5].

Since the 1990s, much emphasis has been placed in the restoration of these marginal agricultural lands and oftentimes hardwood tree species are planted to recreate approximate pre-settlement conditions, increase soil fertility, sequester carbon, increase forest connectivity, improve wildlife habitat, and potentially provide future income via harvest [6–9]. In particular, *Quercus* species are commonly targeted in afforestation projects worldwide. There is an increasing concern about the long-term sustainability of *Quercus* dominated forests, both in the United States and in other areas of the world [10,11]. The successful conversion of marginal agricultural lands may help to counteract the compositional decline of *Quercus* species.

Afforestation success relies upon a number of factors including competition, herbivory, planting technique, soil properties, and seedling stock characteristics [2,12,13]. Generally, forest managers assume that seedling survival through the establishment phase (1–5 years after planting) is an indicator of afforestation success and therefore most studies have focused on plantings that are less than 10 years of age [14–17]. While initial establishment is critical for the development of plantations, less is known about the long-term impacts of the initial planting treatments and site conditions.

Recent observations suggest that stands once considered beyond the establishment phase and successfully afforested are increasingly impacted by invasive, exotic species, hereafter invasive species. Two invasive species in particular, *Elaeagnus umbellata* (autumn olive) and *Lonicera japonica* (Japanese honeysuckle), are abundant across a wide range of disturbed landscapes in eastern United States including areas where afforestation is a common land use. *Elaeagnus umbellata* is an invasive shrub that can form dense and monospecific stands with heights of three to five meters, reducing native plant species productivity and diversity [18]. *Lonicera japonica* is a vine that often occurs in densities capable of strangling and deforming young trees at the main bole, toppling them and forming dense vegetative mats that may establish a state of arrested succession [19]. Alternatively, successful afforestation may pre-emptively capture resources and niches (Empty Niche Hypothesis, Fluctuating Resource Hypothesis) otherwise conducive to the establishment of invasive species such as *E. umbellata* and *L. japonica* [20].

Due to the contrasting effects of invasive species reported for afforestation projects managers need to know how planted trees are impacted by invasive species and whether management strategies require adjustment to accommodate emerging threats to stand development. This study used 15 to 18 year old *Quercus* plantings located on abandoned agricultural sites in southern Illinois to evaluate the impacts of pre-afforestation land use and presence of woody invasive species on young *Quercus* stands.

2. Experimental Section

2.1. Research Area

This study was conducted at Crab Orchard National Wildlife Refuge in Williamson County, Illinois, USA. Average temperature for the area is 14 °C with annual precipitation averaging 112 cm of rain and 26–38 cm of snow [21]. Vegetative communities within the Refuge include upland *Quercus-Carya* forests, bottomland *Acer-Fraxinus* forests, *Pinus* plantations, restored prairies, agricultural fields both fallow and annually row cropped, and shrub lands [21]. Historically, farmers would lease land from the Refuge for crop production. While this still occurs, managers have terminated agricultural production on marginal sites in order to increase wildlife habitat and hardwood forest cover.

Twenty-nine sites were afforested during 1995–1998. Slopes on the sites range from 0% to 5% and soils across the sites are dominated by moderately well drained, fine, silt loams (Rend series, mesic Fragic Oxyaquic Hapludolfs). These characteristics are typical of many agricultural fields throughout the region. Site index ranges from 15 to 17 meters tall at a base age of 50 years for *Quercus alba* (white oak).

Quercus spp. seedlings were mechanically planted with healthy, 1–0 root stock on a spacing of 3.7 meters between rows and 2.4 meters between trees (1122 trees per hectare) [22]. Planting sites varied in size from 0.8 hectares to 11.2 hectares with four distinct previous land cover types (LCT) including: Clover (11 sites), Soybeans (6 sites), Woody Brush (5 sites), and Herbaceous Weeds (7 sites). Woody Brush sites were dominated with early successional, native volunteer hardwood tree species and *E. umbellata*. Herbaceous Weed sites were dominated by *Festuca* and *Solidago* species. Prior to planting, all but one of the Woody Brush sites received a glyphosate herbicidal application the fall before spring planting and mowing/bush-hogging prior to planting. The other Woody Brush site received herbicide treatment but no mowing. Four of the seven Herbaceous Weeds sites received an herbicide pre-planting treatment, two of which were also mowed. Only one of the eleven Clover sites received a pre-planting treatment (mowing) and all of the Soybean sites were untreated.

2.2. Sampling

Fixed radius circular plots of 0.02 ha were used to sample each site. Plot locations were established on a 50 by 50 m grid prior to going out into the field. Approximately 5 percent of each site was sampled and a total of 219 plots were sampled across the research sites. In every plot tree species, diameter class (<2.5 cm, 2.5–7.6 cm, 7.6–12.7cm, >12.7cm) at breast height (DBH), and existence of a vine on the main bole (vine attachment) were recorded for each individual trees greater than 1.37 m in height. In addition to the previous measurements, DBH was recorded for individual *Quercus* stems, as well as, a determination of free-to grow status. A tree was deemed free-to grow if its crown was overtopped by competing vegetation in one or less of its four quadrants. Finally, at each plot, cover (%) of two invasive species, *E. umbellata* and *L. japonica*, were visually estimated and DBH was measured for the dominant *E. umbellata* stem for each rootstock.

2.3. Statistical Analysis

Response variables (*Quercus* density and DBH, free-to-grow *Quercus* density and DBH, *E. umbellata* density and cover, and *L. japonica* cover) were analyzed with ANOVA using a model comprised of two factors (mixed procedure; [23]). LCT (factor 1) was fixed and site (factor 2; nested within LCT) was random. Statistical significance for all tests was set at $\alpha = 0.10$. When ANOVA revealed a clear difference between the LCT, we used the probability of difference (PDIFF) option for post-hoc pairwise comparisons. Regression was used to compare the relationship of total tree density and invasive cover and total tree density and vine attachment.

2.4. Afforestation Success

Stem density for all native woody species was combined with basal area to determine the stocking status using a regional upland stocking guide with afforestation classified as successful if total native tree stocking exceeded 58 percent [24]. Stocking success was also determined for free-to-grow *Quercus*. Sites were considered successfully stocked with *Quercus* if they contained at least 124 free-to-grow *Quercus* stems per hectare [22,25].

3. Results

3.1. Tree Species

Eleven *Quercus* species were observed throughout this study (Table 1). The most abundant were *Q. alba*, *Q. palustris* (pin oak), *Q. macrocarpa* (bur oak) and *Q. rubra* (Northern red oak) which accounted for 78 percent of *Quercus* stems measured. Total *Quercus* density on the twenty-nine sites ranged from 0 to 529 stems/ha with a mean density 252 stems/ha and a mean DBH of 6.7 cm. There was a significant difference in total *Quercus* density ($F = 4.86$, $p = 0.01$) among the four LCT (Figure 1). Among the four LCT, total *Quercus* density was significantly higher in Soybeans and Clover sites compared to Woody Brush sites ($p = 0.02$ and 0.05, respectively). Soybean sites also had nominally higher total *Quercus* density compared to Herbaceous Weeds sites ($p = 0.066$). Free-to-grow *Quercus* density also differed significantly among LCT (Figure 1; $F = 3.71$, $p = 0.03$). Soybean sites had significantly more free-to-grow *Quercus* stems/ha compared to Woody Brush and Herbaceous Weeds sites ($p = 0.05$ and $p = 0.09$, respectively). There was no significance among the four LCT regarding DBH for both all *Quercus* stems and free-to-grow *Quercus* stems (Figure 2; $F = 2.15$, $p = 0.11$, $F = 1.48$, $p = 0.25$, respectively).

Table 1. List of *Quercus* species recorded, their abundance (percent) in each DBH category, total number of trees sampled of that species, and the number of sites occupied for all sampled *Quercus* trees ≥1.37 m in height.

Species	<2.5 cm	2.5–7.6 cm	7.6–12.7 cm	>12.7 cm	Total trees sampled	# of sites occupied
Q. alba	20	43	27	9	411	26
Q. palustris	11	40	31	17	252	22
Q. macrocarpa	39	45	15	2	137	23
Q. rubra	13	52	28	7	127	13
Q. bicolor	3	26	40	30	99	8
Q. velutina	29	32	25	14	72	14
Q. shumardii	11	68	16	5	38	3
Q. imbricaria	42	32	26	0	31	10
Q. muehlenbergii	27	27	27	18	11	3
Q. acutissima	25	0	25	50	4	1
Q. michauxii	0	100	0	0	1	1
Total	19	42	27	12	1,183	28

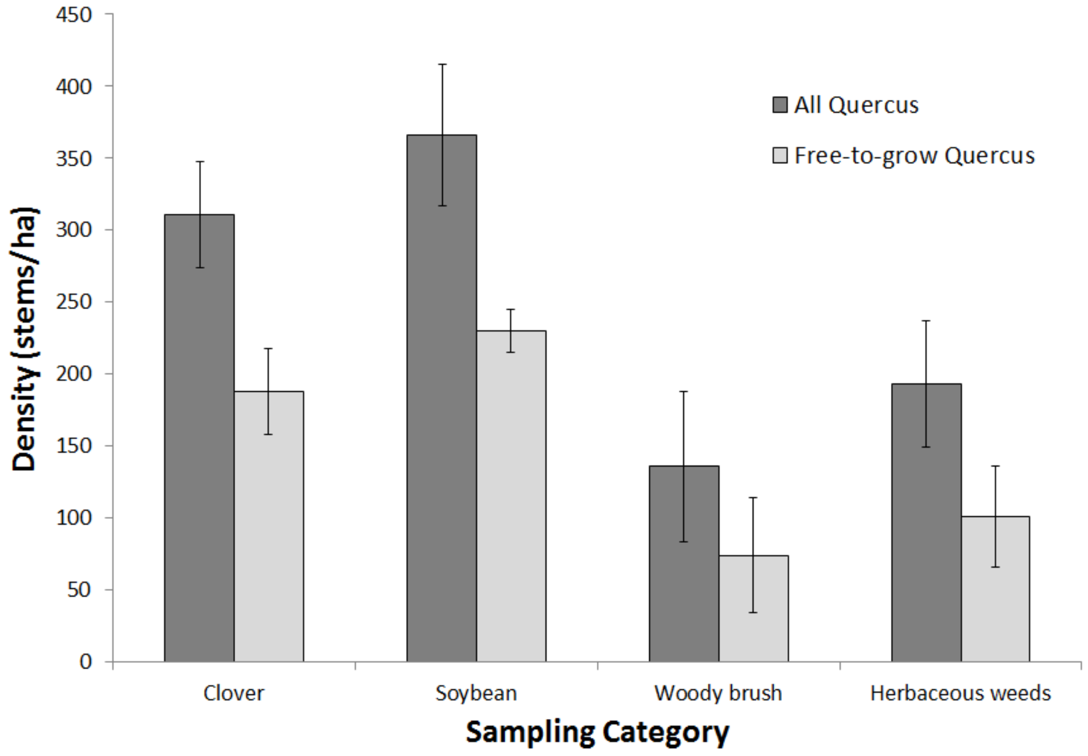

Figure 1. Density (stems/ha ± S.E.) of all *Quercus* stems and free-to-grow *Quercus* stems by Land Cover Type (LCT). Across LCT, there was a significant difference in total *Quercus* density and free-to-grow Quercus *density*, F = 4.86, p = 0.01 and F = 3.71, p = 0.03, respectively.

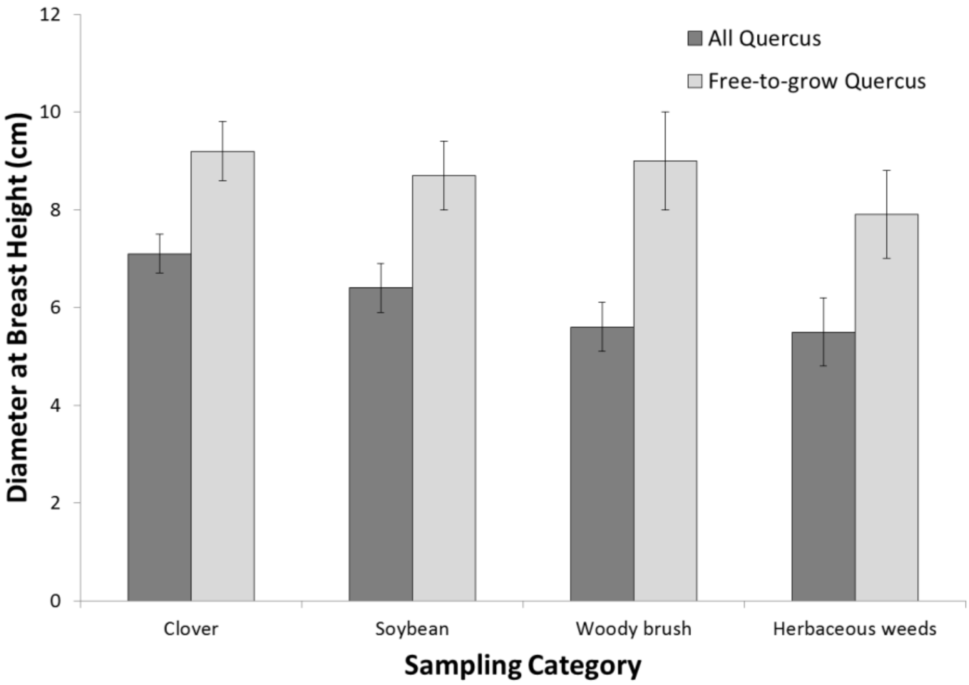

Figure 2. Diameter at breast height (DBH; ± S.E.) of all *Quercus* stems and free-to-grow *Quercus* stems by Land Cover Type (LCT). There was no significance among the four LCT regarding DBH for all *Quercus* stems and free-to-grow *Quercus* stems, F = 2.15, $p = 0.11$, F = 1.48, $p = 0.25$, respectively.

Thirty-five other tree species were present on the study plots with heights at or above breast height. Several were present throughout all or most of the sites including *Ulmus americana* (American elm), *Liquidambar styraciflua* (sweetgum), *Acer rubrum* (red maple), and *Fraxinus* spp. (white and green ash) and *Acer negundo* (boxelder) (Table 2). *Fraxinus* spp. and *U. Americana* were most common in the smaller size classes (<2.5 cm and 2.5–7.6 cm). While these species remained present in the larger size classes *L. styraciflua* was most abundant in the largest size classes, accounting for 20 and 36% of 7.6–12.7 cm and >12.7 cm stems, respectively (Table 2).

Table 2. Alphabetized list of the ten most common native, volunteer tree species present (excluding *Quercus* species & *Elaeagnus umbellata*) and abundance (percent) within each of the four DBH categories.

Species	<2.5 cm	2.5–7.6 cm	7.6–12.7 cm	>12.7 cm
Acer negundo	3	3	6	4
Acer rubrum	9	13	9	3
Diospyros virginiana	2	3	7	0
Fraxinus spp.	16	17	11	4
Juniperus virginiana	0	6	9	4
Liquidambar styraciflua	6	8	20	36
Rhus copallina	3	5	0	0
Ulmus alata	5	4	0	0
Ulmus americana	49	31	18	11

3.2. Afforestation Success

Free-to-grow *Quercus* afforestation was most often successful on Clover and Soybean sites (82%) compared to 20% of Woody Brush and 24 percent of Herbaceous Weed sites (Figure 3). Stocking success, percentage of sites that met criteria stated in Experimental Section 2.4, for all native tree species was greatest on Clover and Soybean sites (>83%) while Herbaceous Weed sites were only successful about 43 percent of the time and no fully stocked Woody Brush sites were recorded (Figure 3).

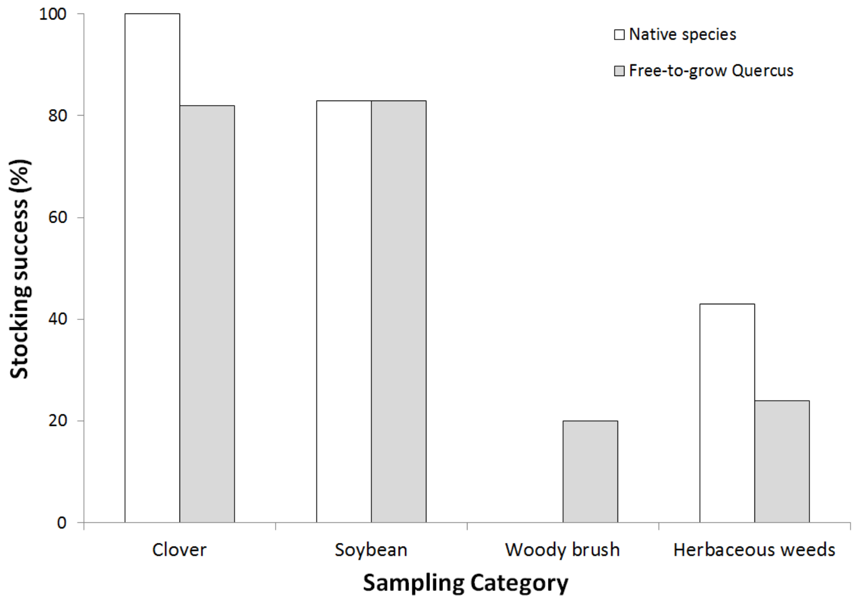

Figure 3. Stocking (%) success for all native tree species and free-to-grow *Quercus* stems by Land Cover Type (LCT).

3.3. Invasive Species

Native species tree density and invasive species cover was negatively correlated (Figure 4; $r^2 = 0.62$). *Elaeagnus umbellata* was observed on 24 of the 29 sites and density was significantly greater on Woody Brush sites (843 stems/ha) compared to all other LCT (<290 stems/ha; F = 4.60, $p = 0.010$). Estimated cover of *E. umbellata* showed a similar result, with the cover on the Woody Brush sites (44 percent) significantly greater than all other sampling categories (<10%; F = 5.93, $p = 0.003$). *Lonicera japonica* was present within 28 of the 29 sites. Mean cover ranged from 9 to 15 percent, but no significant differences in cover were observed across the four LCT (F = 0.40, $p = 0.756$). However, the tree density was negatively correlated with vine attachment (Figure 5; $r^2 = 0.32$).

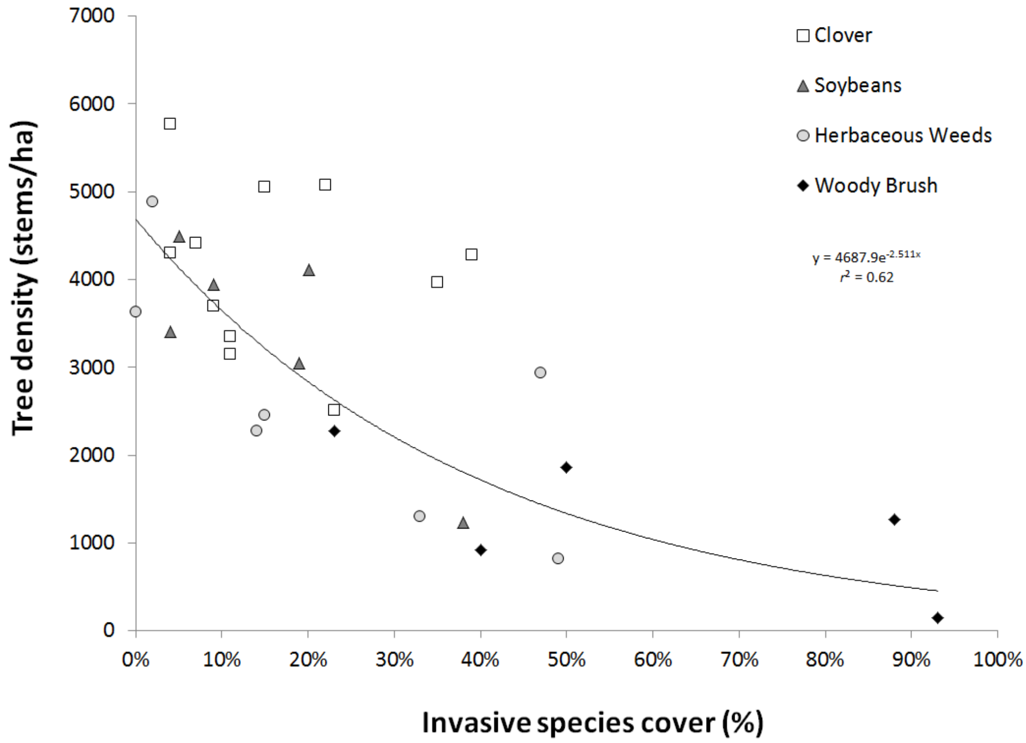

Figure 4. Relationship between native species tree density and invasive species cover (r^2 = 0.62). Land Cover Types (LCT) are distinguished by unique symbols for each LCT.

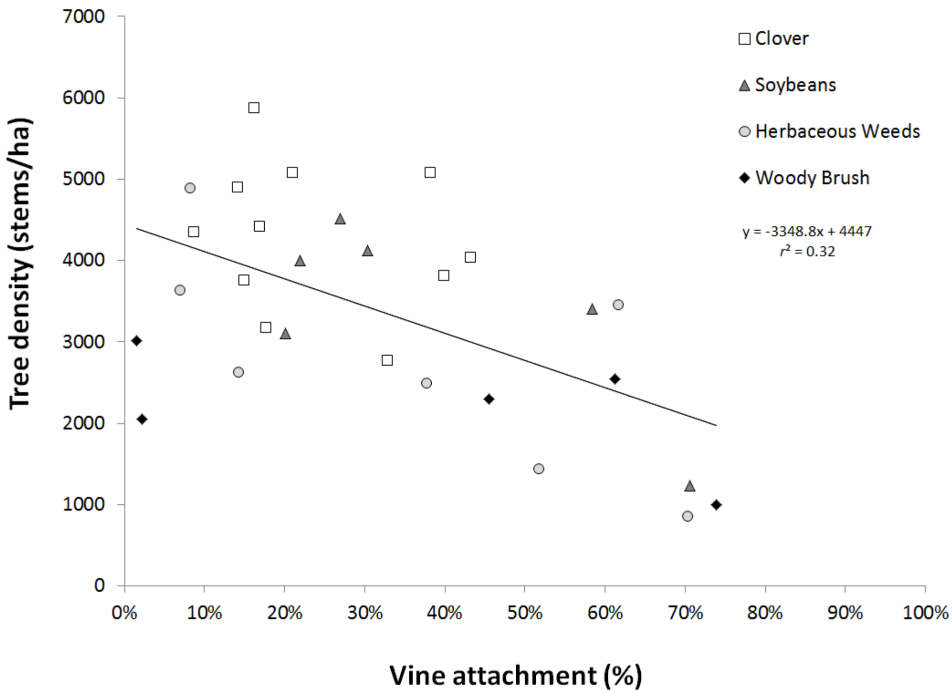

Figure 5. Relationship between tree density (including *Elaeagnus umbellata*) and vine attachment (%) on those trees. Tree density was negatively correlated with vine attachment (r^2 = 0.32). Land Cover Types (LCT) are distinguished by unique symbols for each LCT.

4. Discussion

Light-seeded angiosperms *L. styraciflua*, *U. americana*, *Fraxinus* spp., *Platanus occidentalis* (sycamore), and *Liriodendron tulipifera* (yellow-poplar) are common volunteer species found on afforested sites originating from seed sources and root stock arising from nearby forest edges. Since the 1960s similar tree species composition has been observed on afforested agriculture lands within the study region suggesting their resiliency as major forest components [26,27]. Historically, these tree species were thought to likely be the main competitors of *Quercus* species in eastern United States afforestation scenarios when they reach larger sizes [28,29]. However, we observed a relationship between tree density and invasive cover and vine presence (Figures 4 and 5, respectively) suggesting that further research is needed to determine the potentially beneficial roles of volunteer native tree species as suppressors of the invasive species that compete with planted *Quercus* species as stand development progresses. Considering the slow development of *Quercus* height and canopy cover relative to the native volunteer species, *Quercus* species would be the most vulnerable to unchecked development of vine and shrub competitors and therefore are among the most likely native tree species to benefit from their suppression.

Elaeagnus umbellata dominated sites were associated with low total tree density and *Quercus* density suggesting that this invasive was at least partially responsible for afforestation failure. Dense thickets of *E. umbellata*, have been associated with exclusion of native species [30,31]. When *E. umbellata* is present on the site prior to planting native species it may overtop and outcompete vegetation, including trees [32]. Decreased restorative success was attributed to the presence of *E. umbellata* of a native tree planting on a brush removed, compacted, surface mine in Virginia, USA [33].

A higher incidence of successful stocking, for both all species and *Quercus* species, was observed on Soybean and Clover sites compared to sites that were fallow prior to afforestation. Though the Clover sites in our study were not planted as cover crops and the Soybean sites were not truly bare soil when planted, these results support the conventional wisdom among foresters associating cover crops and bare soil at the time of planting with low tree mortality and better tree growth [34]. Residual soil nitrogen from both leguminous clover and soybeans may have contributed to increased tree growth [12] and therefore success. Jacobs *et al.* [14] noted that mechanical/chemical pre-planting treatments resulted in significantly higher *Quercus* seedling survival and [35] stated that site preparation is vital in afforesting areas formerly in agricultural production. Although not intentionally conducted as a site preparation operation, intensive agronomic row cropping prior to afforestation was associated with a similar response in the present study. While mowing and herbicidal spraying were used as site preparation techniques within this study, further pre-and post- planting treatments are advisable to ensure success [36].

Sites left fallow for at least one growing season typically support a variety of early successional grasses, vines, shrubs and trees. This established vegetation, with better-developed shoots and roots might jeopardize planting success. When considering candidate sites for afforestation, avoiding sites that are heavily impacted with aggressive invasive species, such as *E. umbellata*, appears to be warranted even following the application of conventional site preparation treatments. Despite being mowed and sprayed with herbicide, these sites were successful only 20 percent of the time compared to sites formerly cropped in soybeans or clover with no other site preparation where the free-to-grow

Quercus afforestation success rate exceeded 80 percent. These results suggest further treatments are necessary to help achieve restorative success where vegetative cover is already established. Accordingly, local foresters have long avoided attempts to establish *Quercus* in communities dominated by sod-forming grasses and brush. McLane *et al.* [37] noted that *E. umbellata* and other aggressive woody exotic species can invade and persist during several successional stages highlighting the need for post-establishment monitoring of restored bottomland forests in infested landscapes.

The negative relationship between total tree density and vine attachment suggests the value of establishing trees early after abandonment to help preclude vine establishment. The negative association between tree cover and incidence of vine attachment (Figure 5) suggests that *L. japonica* is likely playing a key role in the potential strangling of trees in these plantation sites. The presence of *L. japonica* along with the abundance of *Campsis radicans* (trumpet creeper) on many sites, is similar to those reported in Louisiana [38], suggesting that planted tree establishment and dominance is too slow to prevent vine invasion and impact on planted trees.

The negative association between invasive species cover and tree density portends expanding invasive plant species dominance as *Fraxinus* are killed as the emerald ash borer (*Agrilus planipennis*) outbreak expands within the study area, and eliminates this important native canopy component [15]. Similarly, Dutch elm disease (*Ophiostoma ulmi*) poses a threat to the long term survival of the *Ulmus* population within these stands. Epidemics of tree diseases and insect outbreak pose an extended or repeated threat to stand development beyond the usual period of vulnerability during stand establishment. Impending loss of these native tree species suggests managers may consider pre-emptive control of invasive species where these species may play a suppressive role.

The increasing presence of invasive species within this landscape appears to be constraining afforestation success. In invaded sites, land managers will need to divert resources from tree planting toward managing invasive species through site preparation and post-establishment vegetation management. Where afforestation is expected to be successful, ensuring that newly established stands quickly attain and maintain continuous canopy cover will decrease the costs associated with preventing invasion by non-native species [39]. As incentives continue to be offered to private landowners and agencies continue to place emphasis on conversion to native forests, there will continue to be a demand for afforestation of high-value species. Oftentimes these plantings will occur on abandoned agricultural fields as land becomes marginal and markets continually fluctuate. This study indicates that favoring sites recently removed from agricultural production will likely result in higher tree densities, decreased invasive species cover, and greater success of planted tree stock.

5. Conclusions

Previous land use plays a critical role in afforestation success. Our results suggest that sites should be planted as soon as possible following agricultural abandonment in order to prevent invasive plant species from becoming established. In addition, successful forest afforestation requires continued effort, nullifying the convention of planting followed by passive management. Sites should be monitored to identify any potential threats to the long-term success of established goals and objective and post planting treatments, such as herbicides or crop tree release, may be needed to achieve desired levels of favored species.

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Author Contributions

Joshua B. Nickelson led the field work and contributed to the analyses and writing, Eric J. Holzmueller contributed to the study design, analyses and writing. John W. Groninger and Damon B. Lesmeister contributed to the study design and writing.

Conflicts of Interest

The authors declare no conflict of interest.

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