A COST COMPARISON OF FIVE MIDSTORY REMOVAL METHODS

Brian G. Bailey, Michael R. Saunders, and Zachary E. Lowe[1]

Abstract.—Within mature hardwood forests, midstory removal treatments have been shown to provide the adequate light and growing space needed for early establishment of intermediate-shade-tolerant species. As the method gains popularity, it is worthwhile to determine what manner of removal is most cost-efficient. This study compared five midstory removal treatments across 10 acres on two sites in Indiana. The treatments were: manual (chainsaws and brush saws), mechanical (tree mower), herbicide (15-percent triclopyr and 3-percent imazapyr), mechanical plus herbicide, and manual plus herbicide. Financial inputs, consisting of labor hours, equipment maintenance, and material costs, were closely documented. The removal increased light to a mean of 15 percent of an open canopy, and basal area was reduced by 20 ft^2 ac^{-1}. Large equipment was shown to be very costly relative to its efficacy, and could not be recommended unless an individual either has access to less expensive equipment or is working with unusually large and easily accessible stands. In terms of basal area and stems removed, chainsaws and brush saws were more economical and more efficient than the other four treatments.

INTRODUCTION

Tree species intermediately tolerant of shade (i.e., intermediates) and unable to persist under intact and mature hardwood forests are often at a competitive disadvantage when canopy gaps are created. However, preemptive silviculture management can help establish advance regeneration of intermediate species, positioning them to recruit into the next stand after overstory removal (Loftis and McGee 1993, Gould and others 2005). Because advanced regeneration is so critical for oak (*Quercus* spp.) recruitment (Lorimer 1993), much work has been done to develop techniques to encourage that regeneration (Teclaw and Isebrands 1993, Paquette and others 2006). The two-step shelterwood, beginning with a preparatory removal of the shade-tolerant midstories common to many hardwood-dominated stands, has been shown to produce the appropriate light and space conditions for establishment of intermediates (Lhotka and Loewenstein 2009). While intermediates cannot persevere under a full canopy, too much light allows aggressive and competing shade-intolerant species to flourish as well. The slight increase in light intensity from a midstory removal can strike a balance between the extremes, a condition necessary for success (Lockhart and others 2000). Only after the intermediate trees gain a competitive advantage maintainable over both shade-tolerant and aggressive shade-intolerant species, which can take up to 10 years (Loftis 1990), can the final shelterwood overstory removal be conducted.

The primary objective of this study was to determine the most effective method of implementing midstory removal, in terms of financial costs and treatment efficiency. Five treatments were included for comparison: manual (chainsaws and brush saws), mechanical (tree mower), basal bark herbicide (15-percent triclopyr and

[1]Graduate Student (BGB), Assistant Professor of Hardwood Silviculture (MRS), and Adjunct Assistant Professor (ZEL), Department of Forestry and Natural Resources, 715 West State Street, West Lafayette, IN 47906. BGB is corresponding author: to contact, call (765) 914-6063 or email at bgbailey@purdue.edu.

3-percent imazapyr), mechanical plus cut stump herbicide, and manual plus cut stump herbicide. Much of the available literature on thinning does not refer specifically to midstory removals, but to different canopy, basal area, and diameter removals (McCauley and Marquis 1972). Accurate prediction costs are essential to planning, however, so determining the expense of these strategies is important (Olson and others 1978). The tested methods encompass the common range of options accessible to practitioners. By comparing several treatments and separating costs by input, practitioners may interpret these findings with regard to their own objectives, sites, and resources. Trends of cost per basal area or numbers of stems are examined to help extrapolate these results to a broader range of stands, and help illustrate the resiliency of methods between sites.

STUDY AREAS

This study was replicated across two relatively small, albeit quite different, sites. The Cox-Haggerty property is located approximately 2 miles west of West Lafayette, IN, and Purdue University's campus (latitude: 40° 25.7'N; longitude: 86° 58.2'W), and is approximately 6 ac in size. Cox-Haggerty had a pretreatment stem density of 942 ac^{-1}, basal area of 156 ft^2 ac^{-1}, and a quadratic mean diameter of 8.3 inches. Soil is Miami silt loam, a moderately well-drained soil. By stem count the overstory (diameter at breast height [d.b.h.] > 6.0 in.) composition was dominated by oak (46 percent), of which 33 percent was white oak (*Q. alba* L.), and 8 percent was northern red oak (*Q. rubra* L.). Hickory (*Carya* spp.) accounts for 20 percent of the overstory, and sugar maple (*Acer saccharum* Marsh.) 5 percent. The midstory (d.b.h. >0.5 in. or ≤6.0 in.) was dominated by sugar maple (36 percent), and Amur honeysuckle (*Lonicera maackii* [Rupr.] Herder) (27 percent); Ohio buckeye (*Aesculus glabra* Willd.) accounted for 8 percent.

The second study area is located at Purdue's Samuel G. Meigs Farm, hereinafter referred to as "Meigs Farm," approximately 8 miles south of West Lafayette, IN (latitude: 40° 17.3'N; longitude: 86° 52.5'W). Meigs Farm is approximately 10 ac and had a pretreatment stem density of 494 ac^{-1}, a basal area of 113 ft^2 ac^{-1}, and a quadratic mean diameter of 10 inches. Soil class is predominately Crosby-Miami and Richardville silt loam, with pockets of the poorly drained Mahalasville-Treaty complex. By stem count the overstory composition was dominated by hickory (54 percent), elm (*Ulmus* spp.) (24 percent), and black cherry (*Prunus serotina* Ehrh.) (10 percent). The midstory comprises elm (65 percent), and hackberry (*Celtis occidentalis* L.) (12 percent).

METHODS

In summer 2008, six approximately 197-ft x 197-ft treatment plots were laid out at Meigs Farm, and six approximately 131-ft x 197-ft treatment plots at Cox-Haggerty. Within each plot, buffered by at least 33 ft from any side to alleviate edge effects, a single measurement plot was centered. Within the measurement plot, a complete inventory of overstory trees was taken. At each corner of the measurement plot, 33-ft x 33-ft subplots were installed to sample the midstory.

In March and April 2009, we implemented five different midstory removal techniques, randomly applied to one of the six treatment plots at each site, leaving the remainder as an untreated control. Unfortunately, we deemed within-site replication unfeasible, largely due to the small acreage of each study area and the importance of keeping fairly large treatment plot sizes for long-term monitoring of tree regeneration response. Furthermore, we felt that plots smaller than those used may not easily accept the larger mechanical equipment. Therefore, since there were only two replications of each treatment, no mean separation statistics are presented.

For manual treatments we used a Stihl MS 260 chainsaw, a Husqvarna 575XP chainsaw, and two Stihl X-series 345F brush saws. Brush saws were used on smaller-diameter stems (generally < 4.0 in. d.b.h.), while chainsaws were used on the rest. The mechanical treatments were conducted using a New Holland model 7610 4wd, 90 hp tractor equipped with a Brown 2620 Folding Deck Tree Cutter attachment (Brown Mfg. Corp., Ozark, AL), followed by cleanup with a chainsaw to clear trees that were missed by or inaccessible to the tree mower. For the herbicide-only treatment, a backpack sprayer was used to spray a basal bark application using a mixture of 15-percent triclopyr (Garlon 4 Ultra®; DowAgroSciences), 3-percent imazypyr (Stalker®; Cyanimad), and 82-percent Ax-It® (Townsend Chemical) bark oil. For both the manual and mechanical plus herbicide treatments, the same herbicide mixture was applied to cut stumps using smaller 6.8 fl. oz. hand sprayers.

Labor was split between either one- or two-person crews. Manual treatments had either one individual running the brush saw while a second person operated a chainsaw, or one person first using the brush saw before switching to a chainsaw. For the manual plus herbicide treatments, the saw operators were able to carry the hand sprayers, and spray each stump immediately after cutting. Mechanical treatments were installed with one tractor operator, plus another individual coming in after the tractor to clear missed or inaccessible stems with a chainsaw. The individual would also spray the stumps cut by the Tree Cutter when prescribed. Herbicide treatments were implemented with one or two individuals carrying backpack sprayers, working independently throughout the plot.

Energy inputs, including labor, petroleum, herbicide, and type and time of equipment used, were recorded for each treatment. To evaluate costs we assumed set rates for labor (\$20 hr^{-1}), herbicide (\$38.04 gal^{-1}), and fuel (\$2.80 gal^{-1}). Equipment costs were based upon rental prices. While some equipment is commonly owned by many practitioners, the larger tree mower is not. Equipment costs were estimated using rental rates to avoid the complexities of life span and maintenance cost assumptions. Equipment rental rates were: brush saw, \$30 day^{-1}; chainsaw, \$8 day^{-1}; herbicide sprayer, \$15 day^{-1}; and tree mower, \$675 day^{-1}.

We used hemispheric photography to measure the effectiveness of midstory removal treatments to increase light availability. In August 2009, eight photos were taken within each treatment plot using a Canon EOS (SLR) 20D digital camera with a Sigma F3.5 EX DG 8mm circular fisheye lens, mounted on a tripod 3.3 ft above the ground. Images were analyzed with Gap Light Analyzer software version 2.0 (Millbrook, NY) to estimate canopy openness by treatment. Canopy openness is defined as percentage of unobscured sky (Raaimakers and others 1995). A Tukey's HSD test was used to compare canopy openness between removal treatments and the control ($\alpha = 0.05$).

RESULTS

LIGHT AND STAND STRUCTURE

All removal treatments showed significantly higher canopy openness levels than the control ($p < 0.05$). Mean canopy openness increased 111 percent between the midstory removal treatments and the control plots (Fig. 1). Understory mean light transmission within the controls was 7 percent of open sky on both sites, and between 14 and 17 percent within the midstory removal treatments. Basal area was reduced by a mean of 20 $ft^2\ ac^{-1}$ or 12 percent on both sites, and stem densities were reduced by a mean of 62 percent at Meigs Farm and by a mean of 70 percent at Cox-Haggerty.

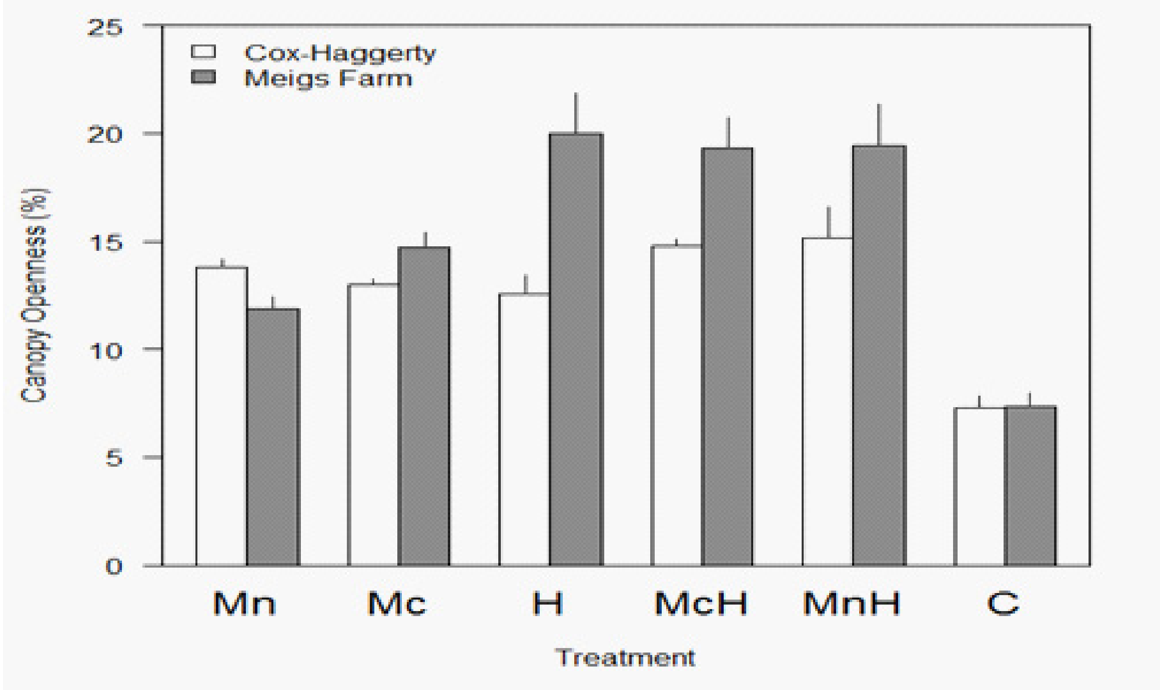

Figure 1.—Percent open canopy by site and treatment with standard error bars shown. Treatments: manual (Mn), mechanical (Mc), herbicide (H), mechanical plus herbicide (McH), manual plus herbicide (MnH), and control (C).

COSTS OF MIDSTORY REMOVALS

Treatment costs ranged from \$36 ac^{-1} to \$406 ac^{-1} (Fig. 2). Between the two extremes, equipment cost of the mechanical treatment alone accounted for 80 percent of the difference (Table 1). Variation in costs for a treatment was driven by stand structure and topographical differences between sites. The largest difference within a single treatment between sites was \$104 ac^{-1}, between the two manual plus herbicide treatments. The Meigs stand had approximately 544 stems ac^{-1} and a slope of zero, while the Cox-Haggerty stand had approximately 958 stems ac^{-1} and steep topographic relief, both factors that regularly impact intermediate stand treatments costs (Wickstrom and Alley 1967). Where herbicide was applied, it cost between \$120 ac^{-1} and \$139 ac^{-1} (Table 1). The exception was in the mechanical treatments, where the equipment shattered most stems, reducing the probability of sprouting enough for us to skip spraying those stems (Ducrey and Turrel 1992).

Cost per square foot of basal area removed ranged from \$2.39 ac^{-1} to \$19.92 ac^{-1}, with the exception of the herbicide treatment at Cox-Haggerty, which cost \$55.50 ac^{-1} (Fig. 3a). In this one case, however, there was an unusually low amount of basal area within that plot to remove, so the estimate appears inflated by the number of stems, and not the work done within. On both sites the manual treatment was clearly the least expensive method per basal area removed. While total cost per acre suggested manual plus herbicide was one of the most expensive treatments (Fig. 2a), on the basis of per unit basal area removed, it was one of the most efficient (Fig. 3a).

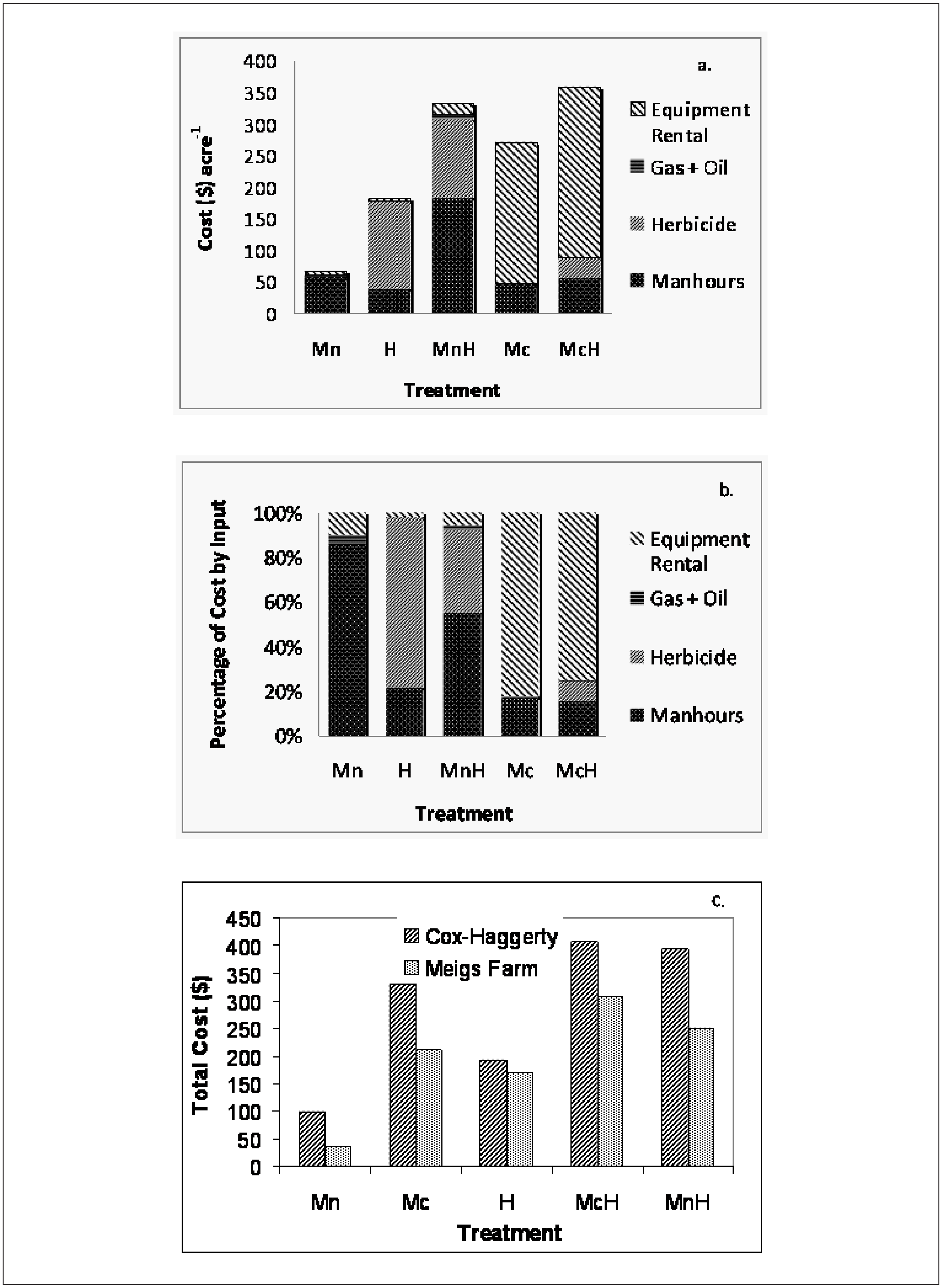

Figure 2.—Mean cost of treatment over both sites, per input (a), percent of mean cost of treatment by input (b,) and total cost of treatment by site (c). Treatments: manual (Mn), mechanical (Mc), herbicide (H), mechanical plus herbicide (McH), manual plus herbicide (MnH).

Table 1.—Total cost ($) and costs ($) per input by treatment. Range shows minimum and maximum observations at Cox-Haggerty and Meigs Farm.

Treatment	Labor	Herbicide	Fuel/Oil	Equipment	Total
Manual	30 - 85	-	2 - 4	4 - 10	36 - 99
Mechanical	36 - 56	-	1 - 2	173 - 272	210 - 330
Herbicide	28 - 50	138 - 139	-	4	171 - 193
Manual and Herbicide	120 - 246	120 - 126	4 - 10	6 - 12	251 - 395
Mechanical and Herbicide	50 - 62	17 - 45	1 - 2	240 - 298	309 - 406

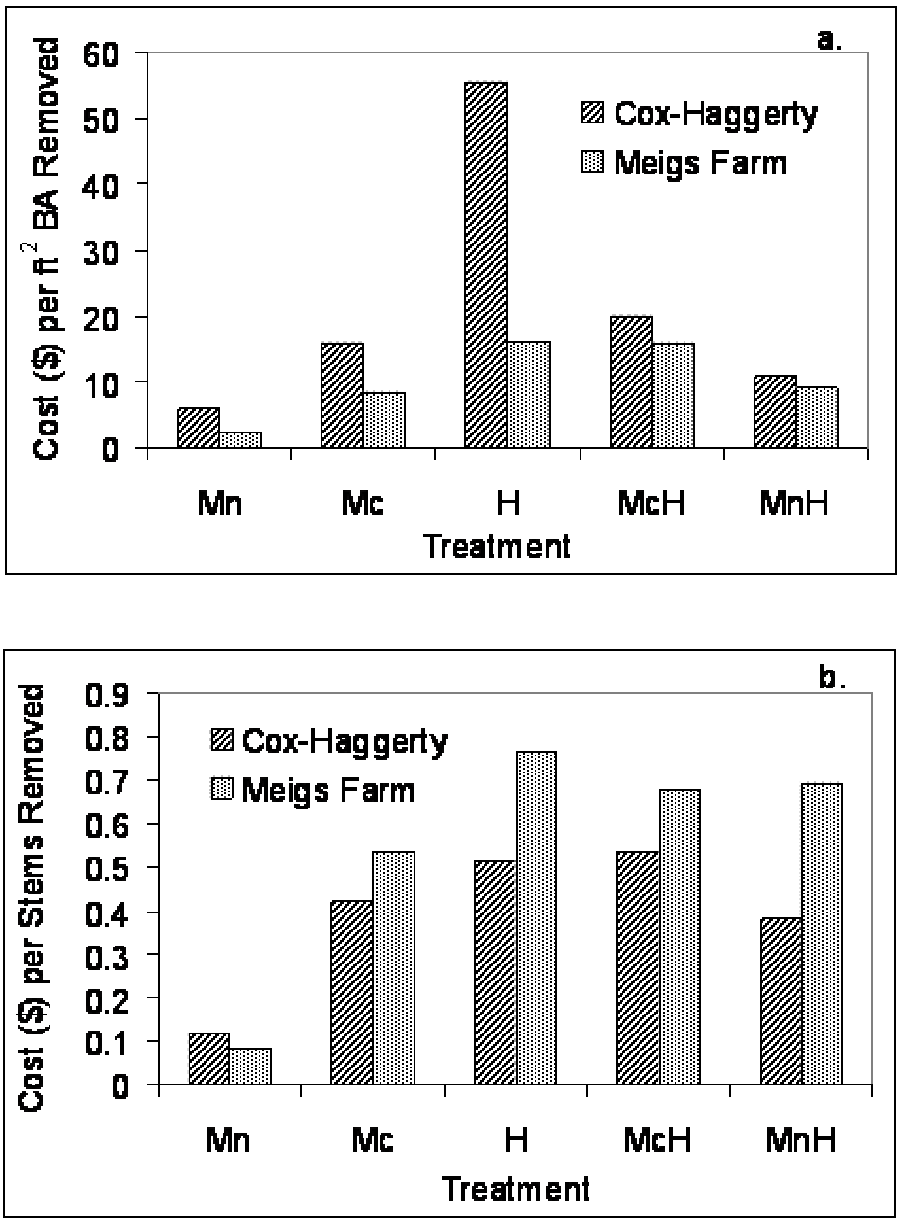

Figure 3.—Cost per square feet of basal area removed (a), and cost per stem removed (b). Treatments: manual (Mn), mechanical (Mc), herbicide (H), mechanical plus herbicide (McH), manual plus herbicide (MnH).

Cost per stem removed also presents the manual treatment as the most cost-efficient (Fig. 3b). The mechanical treatments are very costly on a per-acre basis (between \$210 and \$406 ac^{-1}), but they were not consistently more expensive than the others on the basis of per square foot of basal area removed or per stem removed.

DISCUSSION

The canopy openness within the uncut controls was similar to that found in other mature hardwood stands (<8 percent) (Jenkins and Chambers 1989). Likewise, the midstory removal increased light by approximately the same proportion as other midstory removal treatments previously documented (Lhotka and Loewenstein 2009). Our post-thinning light levels are noteworthy because they correspond well with results from shade cloth experiments, which have repeatedly shown that similar light levels, those nearing 20 percent, cause increases in growth of intermediate-shade-tolerant seedlings (Gottschalk 1994). While midstory removal does not optimize light for optimal seedling growth (Walters and others 1993), the main strategy of midstory removal is to provide a relative growth increase of intermediates compared with the competitive shade-tolerant and shade-intolerant species (Beaudet and others 2004).

Though the mechanical treatments were some of the most expensive, they also showed a degree of resilience to increased stem densities. Cost per stem removed increased 21 percent when mechanical treatments were implemented on a site with high stem densities, but there was a 45-percent increase in cost per stem removed when the manual plus herbicide treatment was implemented on the similar sites. Two reasons help explain this difference, and both are contributing factors worthy of consideration when adopting a prescription for an individual site. The herbicide and herbicide plus manual treatments were most sensitive to stem density, simply because more stems needed to be sprayed. With exceptionally high stem densities to treat (up to 1,000+ ac^{-1}), more herbicide and application time are needed. Second, high stem densities make it difficult to maneuver through a thick understory with a backpack sprayer, which will inevitably slow the technician's progress. Though both reasons add time to workers on foot, it makes little difference in the speed of a mechanical treatment. Even with extremely high stem densities, the cost of the manual treatments would not approach that of the mechanical, but the mechanical could be more cost-effective than the herbicide and manual plus herbicide treatments, particularly on large tracts with flat to moderately sloping terrain.

Each methods had its limitations. The accessibility of the mechanical equipment was limited to slopes less than 15-20 percent, and downed logs impeded the tractor's movement. Chainsaws also had to be used after the mechanical treatment to clean up missed or inaccessible stems. For the herbicide treatments, it was difficult to achieve a complete kill in one pass, particularly during leaf-off conditions. Follow-up treatments are likely necessary. Further, while the manual treatments were less expensive, the efficacy of the treatment has not yet been fully measured. Choosing not to use herbicide will likely result in an increase in the amount of sprouting, particularly for invasive species, in turn potentially jeopardizing the success of the treatment. Sprouts may grow much faster than naturally regenerated or planted desirables, once again becoming competition in a few years (Ducrey and Turrel 1992). When a method is being chosen, assessment is therefore critical in matching the appropriate tools and resources to the site and stand.

As the first step of a shelterwood, midstory removal is often an essential part of the future success of the system. It is therefore important to find a suitable method that fits within the constraints of a manager's resources, yet is still compatible with the site and objectives. By using these data to help inform that decision, managers can achieve better planning and results.

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