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Protection of Ash Trees Under Extended Emerald Ash Borer Pressure

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Abstract

Ten studies were conducted in northeastern Illinois from 2007 to 2015 to evaluate treatment formulations, rates, and application timing and methods for protection of green (*Fraxinus pennsylvanica*), white (*F. americana*) and blue ash (*F. quadrangulata*) trees from the emerald ash borer (EAB), *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae). Annual mid-May, June, July, and September basal soil drenches, basal broadcast applications, and basal trunk spray applications of imidacloprid, clothianidin, dinotefuran used alone, imidacloprid + clothianidin, dinotefuran + clothianidin, and trunk injections of emamectin benzoate were evaluated. Imidacloprid applied alone at 0.57 g a.i./2.54 cm dbh or greater, clothianidin and dinotefuran alone at 0.93 g a.i./2.54 cm dbh or greater, imidacloprid + clothianidin at 0.57 g a.i. + 0.28 g a.i.2.54 cm dbh or greater, dinotefuran + clothianidin at 0.47 g a.i. + 0.46 g a.i./2.54 cm dbh or greater, or emamectin benzoate applied at 0.2 to 0.6 g a.i./2.54 cm dbh provided good protection of ash trees up to 61 cm mean dbh. Canopy thinning was strongly correlated with the number of larval galleries/m^2 ($R^2 = 0.95$; $P < 0.001$) and adult EAB exit holes per m^2 of branch surface area ($R^2 = 0.94$; $P = 0.002$). Severe drought conditions may have contributed to a differential PCL response for treated large green ash trees growing in narrow residential parkways compared to trees growing in open park-like-landscape settings. Choice of active ingredient(s), product formulation(s), application methods and timing, EAB pressure, host susceptibility, and abiotic factors, and their role in implementing an EAB pest management plan are discussed.

Keywords: ash, clothianidin, dinotefuran, emamectin benzoate, emerald ash borer, imidacloprid

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The emerald ash borer (EAB), *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) was initially identified in June, 2002 from beetles collected in the Detroit, Michigan area (Haack et al. 2002, Cappaert et al. 2005, Herms and McCullough 2014). Green ash (*Fraxinus pennsylvanica*) and white ash (*F. americana*) are commonly planted as landscape and parkway trees throughout the eastern and midwestern United States comprising 10% to greater than 30% of the urban forest tree canopy (Raupp et al. 2006). More recently, blue ash (*F. quadrangulata*) is being considered for parkway and landscape plantings (Dirr 2009; author's personal communication with green industry professionals). Currently, chemical treatments are the only effective method for protecting existing ash trees from this insect (Poland and McCullough 2006). Costs associated with ash tree preservation and protection or removal falls on municipalities and property owners (Sydnor et al. 2007, Kovacs et al. 2010, McCullough and Mercader 2012, Creticos 2013). Early on, insecticide trials for EAB were not totally successful, consistent, or reliable, and led to widespread skepticism and rejection by arborists, urban foresters, government decision makers, and property owners as an effective EAB management strategy (Herms et al. 2009). More recently, neonicotinoid insecticide field studies have demonstrated more consistent and reliable means for protecting ash trees from EAB (Cappaert et al. 2005; Smitley et al. 2008, 2010a, b, 2015; Herms et al. 2014; Bick et al. 2018; McCullough et al. 2019; Robinette and McCullough 2019). Recent studies have demonstrated that the cost of tree removal commonly exceeds the cost of insecticide treatment (Sydnor et al. 2007, Kovacs et al. 2010, Sadof et al. 2011, McCullough and Mercader 2012, McKenney et al. 2012, Vannatta et al. 2012, Hauer and Peterson 2017). In addition, trunk injections of emamectin benzoate, used every two to three years, have been shown to be highly effective in protecting ash trees from the emerald ash borer (Smitley et al. 2010a; McCullough et al. 2011, 2019; McCullough and Mercader 2012; Herms et al. 2014; Flower et al. 2015; Lewis and Turcotte 2015; Bick et al. 2018) and are being used by green industry professionals and as general use products for use by homeowners. Other treatment application methods including soil injections, basal soil drenches, basal broadcast applications, and basal trunk sprays of neonicotinoid class insecticides are alternatives available for use by professionals and homeowners alike for EAB management. These treatment methods require minimal equipment, are easier to apply compared to soil and trunk injection methods, and have been shown to be efficacious for both homeowners and green industry professionals for protecting ash trees up to 38 cm dbh (Smitley et al. 2010a, b; McCullough et al. 2011, 2019; Herms et al. 2014, 2019; Bick et al. 2018).

For larger trees over 38 cm dbh, the use of soil injections and basal soil drenches of neonicotinoid insecticides have not always proven to be effective for trees over 38 cm dbh and when under intense EAB pressure (Smitley et al. 2010b). Early on, rates and practices of applying imidacloprid specified a linear relationship between tree dbh and application rates. However, research by LeGoff and Ottorini (1996) and McCullough and Siegert (2007) have shown that as ash tree dbh doubles, tree surface area increases five-fold. These findings suggest the need to increase treatment rates for larger trees to account for the larger surface area and phloem biomass (Smitley et al. 2010b). With EPA approval of the 2× rate of imidacloprid for ash trees with trunk diameters greater than 38 cm, and the availability of additional neonicotinoid insecticides and emamectin benzoate, more reliable protection of ash trees over 38 cm dbh is a possibility. More recent studies by Smitley et al. (2015) and Bick et al. (2018) have shown that a spring and/or fall application of imidacloprid at the 2× rate can be effective in protecting trees over 38 cm dbh from EAB. Therefore, the objectives of this study were to evaluate the efficacy of systemic insecticides (imidacloprid, dinotefuran, clothianidin, and emamectin benzoate) and their combinations for control of the emerald ash borer (EAB) on green, white, and blue ash trees greater than 38 cm dbh by comparing various modes of application (soil application, basal bark spray, trunk injection), rate and number of applications, and timing. More specifically, we evaluated the efficacy of 1× and 2× rates of basal soil drenches of imidacloprid applied alone or in combination with clothianidin plus a 2-1-1 fertilizer; basal broadcast applications of imidacloprid in combination with a 2-1-1 fertilizer; basal soil drenches of clothianidin and dinotefuran each applied alone or in combination; a basal broadcast application of dinotefuran; basal trunk sprays of clothianidin and dinotefuran each applied alone; and trunk injections of emamectin benzoate.

Materials and Methods

Ten different studies, each of at least four years' duration, and consisting of three to seven different treatments per study, were conducted between 2007 and 2015 on green, white, and blue ash parkway and park trees at sites in the greater Chicago, Illinois area. Depending on tree availability, five to ten single tree replicates were established per treatment rate per study site along with an equal number of untreated controls. Trees at each study site were randomly assigned a treatment or were designated an untreated control. Only healthy, pest and disease free, and undamaged trees were selected, and all study trees were in good condition at the beginning of their respective studies. The only abiotic event was the unforeseen 2012 drought which impacted all of the trees in seven of the ten studies. Six of the ten studies included trees less than 50 cm dbh, and four studies included trees greater than 50 cm dbh. Here, trees less than 50 cm dbh less will be treated as smaller trees and trees greater than 50 cm will be considered large. All study trees were evaluated in June and August of each year for percent canopy thinning (nearest 10%) by two individual evaluators as described by Smitley et al. (2008) except for the Homewood and Fermi Lab Village study sites, which were evaluated only once per season. Percent canopy loss (PCL) is used for comparing insecticide efficacy, application methods and timing, and insecticide formulations. A stand-alone fertilizer treatment was not included in the trials because previous studies have shown fertilizer treatments have no effect on ash resistance to EAB (Tanis and McCullough 2015). All Merit and Bayer Advanced Tree and Shrub (BATS) products were formulated by Bayer Corp. (Research Triangle Park, NC, U.S.), Xytect products were formulated by Rainbow Treecare Scientific Advancements, (Minnetonka, MN, U.S.), Safari products by Valent Corporation (Walnut Creek, CA, U.S.), and the TreeAge product was formulated by ArborJet Inc. (Woburn, MA, U.S.). A complete listing, by study site, of the number of single tree replicates (N), chemical treatments by trade name or acronym, rate (total active ingredient per cm dbh) applied per year, application method, and application timing is presented in Table 1. All treatments are identified in the narrative and data tables using trade names and/or acronyms, and their corresponding percent active ingredient.

Skokie, Illinois Study (2007–2011): Thirty large (mean dbh = 58 cm; range = 51–89 cm) green ash parkway trees, growing in Skokie, Illinois, were used to evaluate 1×, 1.5×, and 2× rates of imidacloprid applied

Table 1. List of chemical treatments by study site, number of single tree replicates per treatment (N), trade name or acronym, common name, rate of active ingredient applied per year, and application method and timing.

Study site	N	Trade name Or Acronym	Common name	Rate per year (A.I. g/2.54 cm dbh)	Application method and timing
Skokie (SK) (2007–2011)					
Mean dbh = 58 cm (range=51–89 cm)					
	10	Xytect 75WSP	imidacloprid	0.56	BSD[8] (one 1X application in mid-May)
	10	Xytect 75WSP	imidacloprid	0.84	BSD (one 1.5X application in mid-May)
	10	Xytect 75WSP	imidacloprid	1.12	BSD (one 2X application in mid-May)
Aurora (AU) (2009-2012)					
Mean dbh = 43 cm (range= 30-66 cm)					
	10	BATSC[1]	imidacloprid + clothianidin	0.58 + 0.30	BSD (one mid-May and one mid-June application)
	10	BATSGF1[2]	imidacloprid + clothianidin	0.76 + 0.38	BBA[9] (one mid-May and one mid-June application)+ 2-1-1 fertilizer
	10	BATSC2X[3]	imidacloprid + clothianidin	1.16 + 0.58	BSD (one 2X application in mid-May)
Homewood (HW) (2008-2011)					
Mean dbh = 41 cm (range= 36-61 cm)					
	10	Merit 2F	imidacloprid	0.58	BSD (one mid-May application)
	10	Merit 2F	imidacloprid	0.58	BSD (one mid-Sept. application)
	10	BATSC	imidacloprid + clothianidin	0.58 + 0.30	BSD (one mid-May application)
	10	BATSGF2[4]	imidacloprid + 2-1-1 fertilizer	0.51	BBA (one mid-May application)
	10	BATSGF3[5]	imidacloprid + clothianidin +2-1-1 fertilizer	0.58 + 0.30	BBA (one mid-May application)
Riverside (RV), Hinsdale (HI), Naperville (NV), and Woodridge (WR) (2012-2015)					
Mean RV dbh=61cm (range=51–91 cm) and Mean dbh = 26 cm (range = 18.8-36 cm); Mean HI dbh=51 cm (range=46–91); Mean NV dbh=58 cm (range=51-64); Mean WR dbh=37 cm (range=25-48 cm)					
	10	Merit 2F	imidacloprid	1.16	BSD (one mid-May application at 2X rate)
	10	BATSC	imidacloprid + clothianidin	0.58 + 0.30	BSD (one mid-May application at 2X rate)
	10	BATSGF1	imidacloprid + clothianidin	0.76 + 0.58	BBA (one mid-May application at 2X rate)+2-1-1 fertilizer
	10	BATSGF4[6]	imidacloprid	0.92 + fertilizer	BBA (one mid-May application at 2X rate)
	10	BATSCF[7]	imidacloprid	1.09 + fertilizer	BSD (one mid-May application at 2X rate)

(Continued on next page)

Table 1. (Continued)

Study site	N	Trade name Or Acronym	Common name	Rate per year (A.I. g/2.54 cm dbh)	Application method and timing
Glen Ellyn (GE) (2010-2014)					
Mean dbh=41 cm (range=28-48 cm)					
	7	Arena 50WDG	clothianidin	0.94	BSD (one application in mid-June)
	7	Safari 20SG	dinotefuran	0.94	BSD (one application in mid-June)
	7	Safari 20SG + Arena 50WDG	dinotefuran + clothianidin	0.48 + 0.47	BSD (one application in mid-June)
	7	Safari 20SG	dinotefuran	0.94	BSD (one application in mid-July)
	7	Arena 50WDG	clothianidin	0.94	BTS[10] (one application in mid-June)
	7	Safari 20SG	dinotefuran	0.94	BTS (one application in mid-July)
	7	Safari 2G	dinotefuran	0.94	BBA (one application in mid-June)
Fermi Lab Village (FLV) (2008-2015)					
Mean dbh=44 cm (range=38-50) for small trees; Mean dbh=60 cm (range 50-70 cm) for large trees					
	10	TREE-age (small)	emamectin benzoate (4%)	0.2	T1[11] Quik-Jet (one mid-May injection)
	10	TREE-age (small)	emamectin benzoate (4%)	0.4	TI Tree IV (one mid-May injection)
	10	TREE-age (large)	emamectin benzoate (4%)	0.3	TI Quik-Jet (one mid-May injection)
	10	TREE-age (large)	emamectin benzoate (4%)	0.6	TI Tree IV (one mid-May injection)

Treatment Code
[1]BATSC = Bayer Advanced Tree and Shrub Protect and Feed Concentrate II (one mid-May and one mid-June application)
[2]BATSGF1 = Bayer Advanced Tree and Shrub Protect and Feed Granule II + 2-1-1 fertilizer (one mid-May and one mid-June application)
[3]BATSC2X = Bayer Advanced Tree and Shrub Protect and Feed Concentrate II (one mid-May application at 2X rate)
[4]BATSGF2 = Bayer Advanced Tree and Shrub Protect and Feed Granule II + 2-1-1 fertilizer (one mid-May application)
[5]BATSGF3 = Bayer Advanced Tree and Shrub Protect and Feed Granule II + 2-1-1 fertilizer (1.1% applied as one mid-May application at 0.51 g a.i./cm dbh)
[6]BATSGF4 = Bayer Advanced Tree and Shrub Protect and Feed Granule II + 2-1-1 fertilizer (1.1% applied as one mid-May application at the 2X rate at 0.58 g a.i./cm dbh)
[7]BATSCF = Bayer Advanced Tree and Shrub Protect and Feed Concentrate II + 2-1-1 fertilizer (1.47% applied as one mid-May application at 2X rate)
[8]BSD = Basal soil drench
[9]BBA = Basal broadcast application
[10]BTS = Basal trunk spray
[11]TI = Trunk injection

as a basal soil drench. All three treatments were applied annually in mid-May as a basal soil drench containing Xytect 75WSP (imidacloprid 75%) at either 0.56 gm (1× rate), 0.84 gm (1.5× rate), or 1.12 gm (2× rate) a.i./2.54 cm dbh. Ten single tree replicates were used per treatment rate and an additional ten trees served as untreated controls. Depending on existing soil moisture conditions, the product was diluted in 8–16 L of water and poured around the base of the trunk.

Aurora, Illinois Study (2009–2012): Thirty green ash parkway trees, with a mean dbh of 43 cm (range = 30–66 cm), growing in Aurora, Illinois, were treated with three different treatments with ten single tree replicates per treatment rate. An additional ten trees served as untreated controls. The three treatments included a single basal soil drench application of a homeowner formulation of BATSC2X (imidacloprid 0.74% + clothianidin 0.37%) at the 2× rate in mid-May; two basal soil drench applications of a homeowner formulation of BATSC (imidacloprid 0.74% + clothianidin 0.37%) at the 1× rate made in mid-May and again in mid-June, and two basal broadcast applications of a homeowner formulation of BATSGF1 (imidacloprid 0.76% + clothianidin 0.38% plus a 2-1-1 fertilizer) made in mid-May and again in mid-June. The two BATSC basal soil drench treatments were diluted in 4–12 L of water, depending on existing soil moisture conditions, and applied to the soil around the trunk base. The BATSGF1 basal broadcast application was applied evenly on the soil surface within 1 m of the tree trunk, and watered in with 4 L of water immediately after application.

Homewood, Illinois Study (2009–2012): Fifty green ash parkway trees, with a mean dbh of 41 cm (range of 36–61 cm), growing in Homewood, Illinois, were treated with five different treatments with ten single tree replicates per treatment rate. Ten additional trees served as untreated controls. The five treatments included either one single mid-May or one single mid-September basal soil drench of professional Merit 2F (imidacloprid 25%); one single mid-May basal soil drench of a homeowner formulation of BATSC (imidacloprid 0.76%+clothianidin 0.58%); or one single mid-May basal broadcast application of either a homeowner formulation of BATSGF2 (imidacloprid 1.1% plus a 2-1-1 fertilizer) or BATSGF3 (imidacloprid 0.55% + clothianidin 0.275% plus a 2-1-1 fertilizer). The basal soil drenches of professional Merit 2F and BATSC were applied by diluting the product in approximately 4.0 liters of water and drenching evenly around the base of the trunk. The basal broadcast application treatments were applied evenly in a circle within 1 m of the tree trunk and immediately watered in with 4 L of water.

Riverside, Hinsdale, Naperville, and Woodridge, Illinois Studies (2012–2015): The Riverside site included 60 large (mean dbh = 61 cm; range = 51–91 cm) green ash trees growing in a park setting, and the Hinsdale site included 60 large parkway green ash trees (mean dbh = 51 cm; range = 46–91 cm). There were ten single tree replicates for each of the five treatment rates, and an additional ten trees served as untreated controls at each site. The Riverside blue ash study site consisted of 36 blue ash parkway trees (mean dbh = 26 cm (range = 19–36 cm) with six single tree replicates for each of the five treatment rates, and an additional six trees served as untreated controls.

The Naperville and Woodridge studies focused on the protection of 25 white ash parkway trees at each site with a mean dbh of 58 cm (range = 51–64 cm) and 37 cm (range = 25–48 cm), respectively. There were five single tree replicates for each of the five treatment rates, and an additional five trees at each site served as untreated controls. The five treatments were applied at the 2× rate at each of the five study sites (i.e. Riverside, Hinsdale, Naperville, and Woodridge), and consisted of an annual mid-May basal soil drench of professional Merit 2F (imidacloprid 25%), a mid-May basal soil drench homeowner formulation of either BATSC (imidacloprid 0.76% + clothianidin 0.58%) or BATSCF (imidacloprid 1.47% plus a 2-1-1 fertilizer), and basal broadcast applications of a homeowner formulation of either BATSGF1 (imidacloprid 0.76% + clothianidin 0.58% + 2-1-1 fertilizer) or BATSGF4 (imidacloprid 1.1% plus a 2-1-1 fertilizer). The basal soil drench applications were applied as previously described by diluting the product in approximately 4 L of water and drenching evenly around the base of the trunk. The basal broadcast applications were applied by distributing the product evenly within 1 m from the base of the tree and watering it in with 4 L of water immediately after application.

Glen Ellyn, Illinois Study (2010–2014): 49 green ash parkway trees, with a mean dbh of 41 cm (range = 28–48 cm), were treated with seven different treatments with seven single tree replicates per treatment or treatment combination rate. An additional seven trees served as untreated controls. Treatments included annual mid-June basal soil drenches of Arena 50WDG (clothianidin 50%) used alone, Safari 20SG (dinotefuran 20%) used alone, and Safari 20SG (dinotefuran 20%) plus Arena 50WDG (clothianidin 50%), and an annual mid-July basal soil drench treatment of Safari 20SG (dinotefuran 20%). The basal soil drenches were mixed with water and applied within 0.5 m around the base of the trunk at a rate of 1 L of drench solution per 2.54 cm dbh. Basal trunk sprays of Arena 50WDG (clothianidin 50%) or Safari 20SG (dinotefuran 20%) were applied annually in mid-June or in mid-July, respectively to the trunk until runoff between the soil line and 1.5 m above the soil line, at a rate of approximately 20 ml/2.54 cm dbh using a Solo hand pump sprayer at 10-20 PSI. The single basal broadcast application of Safari 2G (dinotefuran 2%) was applied annually in mid-June, evenly to the soil, within 1m of the trunk and watered in with 4 L of water.

Fermi Lab Village, Batavia, Illinois Study (2008–2015): This eight-year study included a total of 60 green ash trees growing in residential and park areas of Fermi Lab Village (FLV) on the grounds of the Fermi National Accelerator Laboratory (FNAL) at Batavia, Illinois. The study was designed to evaluate the Quik-jet™ and Tree IV™ trunk injection systems of Tree-age (4% emamectin benzoate) for protection of green ash trees. There were ten single tree replicates for each of the four treatment rates, and an additional ten trees served as untreated controls, for each of the two dbh size classes. In mid-May 2008, 40 green ash study trees were selected for treatment and were divided into two dbh size classes (38 to 50 cm, and greater than 50 cm dbh) for a total of 20 trees in each dbh size class treatment group, and were trunk injected. The trees in the small dbh size class treatment group had a mean dbh of 39 cm (range of 36 to 46 cm) and trees in the larger dbh size class treatment group had a mean dbh of 55 cm (range of 48 to 66 cm). Within the small (38 to 50 cm dbh) size class treatment group, ten single tree replicates received a Quik-jet™ trunk injection of Tree-age (4% emamectin benzoate) at 0.2 g a.i. per 2.54 cm dbh in 5 ml of water per 2.54 cm dbh, and a second group of ten trees received a Tree IV™ trunk injection of 0.4 g a.i./2.54 cm dbh in 10 ml of water per 2.54 cm dbh. For the group of 20 larger trees (greater than over 50 cm dbh), ten single tree replicates were trunk injected with Tree-age (4% emamectin benzoate) at 0.3 g a.i. per 2.54 cm dbh in 7.5 ml of water per 2.54 cm dbh with the QUIK-jet™ trunk injection system, and a second group of ten trees received 0.6 g a.i.. per 2.54 cm dbh in 15 ml of water per 2.54 cm dbh using the Tree IV™ trunk injection method. Injection holes were drilled into the tree to a depth of approximately 5.1 cm and a plastic septum (Arborjet #4 plug) was inserted into the trunk at 20–30 cm above the ground. The number of injection sites per tree was determined by taking the dbh and dividing by two. Injection sites were spaced approximately every 15 cm around the trunk circumference. In 2007, an EAB infestation was first detected in green ash trees in the NW corner of the FNAL property. The Fermi Lab Village (FLV) study site was situated approximately 1.2 km east to southeast of the initial EAB infestation so, in mid-May, 2008, ten green ash EAB trap trees were established along a NW to SE transect to monitor for EAB spread and pressure into the FLV study site. At the end of the 2009 and 2010 field seasons, the trap trees and branches from declining portions of untreated non-study FLV trees were felled or removed, peeled, and examined for evidence of EAB galleries and life stages. All 40 of the original study trees were retreated in mid-September, 2012 using the same rates, volume of solution, number of injections sites, and application methods. The 2012 re-application treatments were delayed until mid-September, 2012 due to a record-setting regional drought which prevailed from October, 2011 through August, 2012.

Phloem Utilization by EAB Larvae: Assessments of phloem utilization by EAB larvae were conducted during the winter of 2011-2012 at the Aurora, Homewood, and Skokie study sites by taking branch samples from remaining untreated control trees. Two untreated trees at the Fermi Lab Village site had to be removed due to hazard and new construction and were also used for branch sampling. At all four sites, branch samples were taken at mid-canopy from each of the four cardinal directions (N, S, E, W) and branches ranged from 5 to 13 cm. in diameter and 1.2 to 1.5 m long. Samples were transported back to the Morton Arboretum entomology laboratory and peeled using a draw knife. Following peeling, measurements of EAB larval gallery area per branch, the diameter and circumference of both ends of the branch, length of the branch, the total number of galleries per branch, and the total number of adult EAB exit holes per branch were recorded. EAB gallery area in cm^2 was determined by measuring the length of the gallery multiplied by the mean width (width at the initiation and at the cessation of the gallery). Total available phloem surface area of each branch was calculated using the formula for the surface area of a cylinder (mean branch circumference × branch length). The total number of EAB galleries and total number of adult exit holes per branch surface area was the quotient of the total number of galleries, and adult exit holes, and the total surface area (cm^2) of the branch, respectively. The percent phloem per branch utilized by EAB larvae was the quotient of the total gallery surface area (cm^2) and total surface area (cm^2) of the branch. All area measurements are expressed in m^2.

Statistical Analysis. Data was analyzed using SigmaStat statistical software (Jandel Scientific, 1992). Percent canopy loss means and standard errors (SEM) were calculated for each study year for each treatment within a given study site for all remaining trees. The Shapiro-Wilk test was used to test for normality and the Levene Median test for equal variance. For each year of data at each study site, a one-way ANOVA was performed to determine if there were any differences among treatment means. If treatment differences were detected within a given year at a given study site, the means were separated at the P = 0.05 level using the Dunn's multiple comparison test. A regression analysis was performed to determine the effect of tree size on the efficacy of an annual 1× basal soil drench of imidacloprid for trees at the Homewood and Skokie study sites. A two-way ANOVA was conducted using the professional Merit 2F and all four Bayer Advanced Tree and Shrub (BATS) treatments at the Riverside, Hinsdale, Naperville, and Woodridge study sites to test for the effects of tree size, tree species, and tree size–tree species interaction for percent canopy loss. All percent canopy loss (PCL) ratings were arcsine transformed before analysis to correct for non-normality and heterogeneity of variance (Jandel Scientific 1992). Real mean percentages are presented in the tables.

Results

All study trees at all sites were assessed as healthy (mean PCL < 14%) at the beginning of their respective studies. Overall, EAB pressure, as indicated by changes in percent canopy loss, took from two to four years to reach 50% PCL at the green ash study sites. EAB pressure did not develop on the Naperville and Woodridge white ash or the Riverside blue ash trees with no significant differences in PCL for untreated and treated trees. Final mean percent canopy loss for all untreated trees at the Naperville and Woodridge white ash and Riverside blue ash study sites was 22%, 17%, and 12%, respectively (Table 5).

Skokie Green Ash Study (2007–2011): During the first three years of the study there were no significant differences in PCL for treated and untreated trees. However, by June, 2011, trees treated with Xytect 75WSP at the 1× rate of 0.56 g a.i./2.54 cm dbh had a significantly higher PCL of 38% than a PCL of less than 19% for trees treated at the 1.5× rate (0.84 g a.i./2.54 cm dbh), and the 2× rate (1.12 g a.i/2.54 cm dbh) of Xytect 75WSP (June, $F = 2.2$; $P = 0.04$) (Table 2). By the end of the study in August, 2011, trees treated at the 1.5× and 2× rates of Xytect 75WSP had significantly lower PCL (less than 21%) compared to the untreated controls (42%) (August, $F = 3.4$; $P < 0.04$). The 1× rate of Xytect 75WSP provided an intermediate level of protection (PCL = 28%) (Table 2).

Aurora Green Ash Study (2009–2012): Initial percent canopy loss (PCL) ratings and other general observations indicated EAB pressure was low (PCL less than 7%) on all the Aurora study trees, generally taking approximately two years to build to a level where canopy loss was visually apparent. There were no significant differences among treated trees and the untreated controls in the first two years of the study (PCL less than 24%). However, by June, 2011, significant differences were observed between untreated trees and trees treated with a mid-May, followed by a mid-June, basal soil drench of BATSC and a single mid-May BSD of BATSC2X (June, $F = 2.2$; $P = 0.04$) (Table 3). By August 2011, all treated trees were significantly healthier (PCL of 15% to 31%) (August, $F = 2.8$; $P = 0.03$) compared to untreated trees which were nearly all dead (PCL = 94%) (Table 3). Branch samples taken from untreated trees, during winter, 2011–2012, indicated that EAB pressure at the Aurora site was high and exceeded EAB pressure (i.e. mean number of galleries/m^2) for comparable studies by Anulewicz et al. (2008) for heavily infested ash trees suggesting that, in retrospect, the EAB infestation at the Aurora site was probably more developed than originally perceived (Table 8). The percent canopy loss for all treated trees increased by 14% to 16% by June 2012 compared to 2011, possibly in response to the 2012 drought, but then leveled off or decreased by August, 2012 when late summer rains returned. Our findings are consistent with Smitley et al. (2008) who found that PCL increased by approximately 20% following drought periods. All untreated trees were dead (PCL = 100%) by June 2012. By the end of the trial, the mid-May followed by a mid-June basal soil drench of BATSC provided good protection of ash trees (final PCL = 16%). The mid-May followed by a mid-June basal broadcast application of BATSGF1 or a single mid-May basal soil drench application of BATSC2X were not as effective in protecting ash trees (final PCL less than 38%).

Homewood Green Ash Study (2008–2011): Three years into the study (June, 2010), significant differences in PCL appeared between treated and untreated trees ($F = 3.2$; $P = 0.03$) (Table 4). All five treatments were highly effective in protecting ash trees from EAB (PCL less than 15%). By 2011, when the study ended, the single mid-May or mid-September basal soil drench

Table 2. Evaluation of three rates of a single mid-May basal soil drench (BSD) of Xytect 75WSP (imidacloprid 75%) for protection of green ash parkway trees at Skokie, Illinois (SK). Each treatment has 10 single tree replicates.

TREATMENT Skokie (SK) green ash parkway trees									
Mean dbh = 58 cm (range = 51–89 cm) One single mid-May basal soil drench (BSD) of imidacloprid 75%					**Mean % canopy loss ratings ± SEM[1]**				
	N[2]	**Jun 2007**	**Aug 2008**	**Jun 2009**	**Aug 2009**	**June 2010**	**Aug 2010**	**Jun 2011**	**Aug 2011**
Xytect 75WSP (0.56 g a.i./2.54 cm dbh)	10	13 ± 2.9a	19 ± 2.6a	21 ± 2.8a	29 ± 3.2a	37 ± 2.9a	37 ± 2.9a	38 ± 1.4b	28 ± 2.6ab
Xytect 75WSP (0.84 g a.i./2.54 cm dbh)	10	1 ± 0.2a	6 ± 4.4a	10 ± 2.1a	11 ± 2.3a	11 ± 2.3a	11 ± 2.3a	10 ± 1.7a	20 ± 3.1a
Xytect 75WSP (1.12 g a.i./2.54 cm dbh)	10	3 ± 0.4a	7 ± 3.9a	6 ± 4.4a	11 ± 2.3a	17 ± 4.4a	17 ± 4.4a	18 ± 1.6a	20 ± 1.9a
UTC	10	12 ± 2.7a	16 ± 3.7a	18 ± 4.2a	23 ± 3.5a	28 ± 3.7a	26 ± 3.5a	21 ± 13.9a	42 ± 12.1b
Significance:		NS[3]	NS	NS	NS	NS	NS	**F=2.2 P=0.04**	**F=3.4 P=0.04**

[1]Means followed by the same letter are not significantly different (Dunn's test; P<0.05)
[2]N = number of single tree replicates per treatment rate
[3]NS = Not significant (P<0.05)

Table 3. Evaluation of a single mid-May basal soil drench (BSD) of BATSC (imidacloprid 0.74% + clothianidin 0.37%), a single mid-May basal broadcast application (BBA) of BATSGF1 ((imidacloprid 0.55% + clothianidin 0.275% plus 2-1-1 fertilizer), and a single mid-May BSD of BATSC (imidacloprid 0.74% + clothianidin 0.37%) at the 2X rate for protection of green ash parkway trees at Aurora, Illinois (AU). Each treatment has 10 single tree replications.

TREATMENT Aurora (AU) green ash trees								
Mean dbh = 43 cm (range = 30-66 cm)		Mean % canopy loss ratings ± SEM[1]						
	N[2]	**June 2009**	**June 2010**	**August 2010**	**June 2011**	**August 2011**	**June 20120**	**August 2012**
BATSC (BSD) (two applications in mid-May and early June)	10	6 ± 2.6a	10 ± 2.3a	10 ± 2.3a	28 ± 4.5a	15 ± 3.2a	31 ± 3.3a	16 ± 2.7a
BATSGF1 (BBA) (two applications in mid-May and early June)	10	4 ± 1.6a	15 ± 2.9a	15 ± 2.9a	51 ± 6.1ab	31 ± 4.7a	45 ± 4.2a	37 ± 3.8a
BATSC2X (BSD) (one mid-May application at 2X rate)	10	4 ± 1.4a	19 ± 5.2a	19 ± 5.2a	39 ± 6.7a	22 ± 4.3a	36 ± 3.9a	37 ± 3.8a
UTC	10	6 ± 2.9a	23 ± 3.1a	23 ± 3.1a	94 ± 1.2b	94 ± 1.2b	100 ± 0.0b	100 ± 0.0b
Significance:		NS[2]	NS	NS	**F=2.2 P=0.04**	**F=2.8 P=0.03**	**F=2.4 P=0.04**	**F=3.1 P<0.001**

[1]Means followed by the same letter are not significantly different (Dunn's test; P<0.05)
[2]N = number of single tree replicates per treatment rate
[3]NS = Not significant (P<0.05)

Table 4. Evaluation of a single mid-May and a single mid-September basal soil drench (BSD) of professional Merit 2F (imidacloprid 25%), a single mid-May BSD of BATSC (imidacloprid 0.74% + clothianidin 0.37%), a single mid-May basal broadcast application (BBA) of BATSGF2 (imidacloprid 1.1% plus 2-1-1 fertilizer), or BATSGF3 (imidacloprid 0.55% + clothianidin 0.275% plus 2-1-1 fertilizer) for protection of green ash parkway trees at Homewood, Illinois (HW). Each treatment has 10 single tree replicates.

TREATMENT Homewood (HW) green ash trees Mean dbh = 41 cm (range = 36-61 cm) Mean % Canopy Loss Ratings ± SEM[1]	N[2]	June 2008	June 2009	June 2010	June 2011
Merit 2F (BSD) (one mid-May application)	10	3 ± 2.9a	12 ± 3.2a	4 ± 2.6a	9 ± 4.6a
Merit 2F (BSD) (one mid-September application)	10	0 ± 0.0a	13 ± 2.7a	9 ± 1.7a	6 ± 3.0a
BATSC (BSD) (one mid-May application)	10	8 ± 5.1a	21 ± 4.5a	13 ± 2.6a	25 ± 2.9ab
BATSGF2 (BBA) (one mid-May application)	10	9 ± 1.5a	7 ± 2.9a	8 ± 2.1a	10 ± 3.1a
BATSGF3 (BBA) (one mid-May application)	10	6 ± 3.0a	7 ± 1.5a	14 ± 1.7a	12 ± 6.8a
UTC	10	11 ± 3.4a	19 ± 4.2a	32 ± 4.2b	80 ± 3.3b
Significance:		NS[2]	NS	**F=3.2 P=0.03**	**F=33.5 P=0.03**

[1]Means followed by the same letter are not significantly different (Dunn's test; P<0.05)
[2]N = number of single tree replicates per treatment rate
[3]NS = Not significant (P<0.05)

of professional Merit 2F; the single mid-May basal broadcast application of either BATSGF2 or BATSGF3 were significantly more effective in protecting ash trees (PCL less than 13%) compared to untreated trees ($F = 33.5$; $P = 0.03$). The basal soil drench of BATSC applied annually in mid-May provided intermediate protection (PCL = 25%). 80% of the untreated trees were dead by the end of the study in 2011 (Table 4). In contrast to the Aurora study, good protection of similar size Homewood ash trees was achieved with only a single mid-May basal soil drench or basal broadcast application of imidacloprid alone or in combination with clothianidin. EAB pressure was lower on untreated trees at the Homewood site compared with untreated Aurora trees, and the Homewood study was concluded prior to the onset of the 2012 drought which possibly afforded better protection of the Homewood trees (Table 8). The 25% percent phloem utilization rate for untreated trees at the Homewood site corresponds with low levels of EAB pressure (less than 20%) as defined by Flower et al. (2015).

Riverside Green Ash Study (2012–2015): By the second year of the study (June, 2013), significant differences in PCL appeared between all treated and untreated trees with the exception of those trees treated with a single mid-May basal soil drench of professional Merit 2F (June, $F = 8.7$; $P < 0.001$; August, $F = 6.2$; $P < 0.001$) (Table 5). By August, 2013, PCL peaked for all treated trees and reached 57% for untreated trees. During 2014, PCL for all treated trees leveled off and was significantly lower than untreated trees (2014, June, $F = 3.3$; $P < 0.015$ and 2014, August, $F = 32.9$; $P < 0.001$) which were all dead (PCL = 100%). This trend continued through the 2015 growing season with PCL for treated trees remaining below 21%, and significantly different from the untreated trees (2015, June, $F = 31.2$; $P < 0.001$ and 2015, August, $F = 47.8$; $P < 0.001$) (Table 5). All untreated trees were dead by the end of the study in 2015.

Hinsdale Green Ash Study (2012–2015): Significant differences in PCL were first observed in August, 2014 between untreated trees ($F = 11.4$; $P = 0.04$) and trees treated with either a single mid-May basal soil drench of professional Merit 2F, or a single mid-May basal broadcast application of the homeowner formulation of BATSGF1 (Table 5). Annual mid-May basal soil drench treatments of homeowner formulations of BATSC and BATSCF, and a basal broadcast application of the homeowner formulation of BATSFG4, were not as effective in protecting green ash trees. By August, 2015, when the study ended, the percent canopy loss for trees treated with a basal soil drench of professional Merit 2F, or a basal broadcast application of either BATSGF1 or BATSGF4 provided significantly better protection of ash trees compared to the untreated trees. Trees treated with basal soil drenches of BATSC or BATSCF provided intermediate protection of Hinsdale green ash trees. Percent canopy loss for untreated trees approached 60% by the end of the study (Table 5).

Riverside Blue Ash Study (2012–2015): All of the blue ash study trees were in excellent condition at the beginning of the study (PCL less than 12%). EAB pressure failed to build with PCL on untreated control trees less than 13% after four years. There was no significant difference in PCL between treated and untreated blue ash trees (Table 5). The low PCL associated with the untreated Riverside blue ash trees is consistent with findings by Tanis and McCullough (2012) where they found a higher survival rate of blue ash following an EAB infestation. Unprotected green ash trees in the immediate area around the study site were dying or dead from EAB.

Naperville and Woodridge White Ash Studies (2012–2015): All Naperville and Woodridge white ash study trees were very healthy at the beginning of the study in 2012, with PCLs less than 16% and 10%, respectively. EAB pressure failed to build throughout the study period, at both sites, as indicated by PCL of 22% and 17% for all untreated study trees, respectively. There were no significant differences in PCL between treated and untreated trees at either site over the four-year period (Table 5). Unprotected green ash trees in and around both study sites were dying or dead from EAB.

Glen Ellyn Green Ash Study (2010–2014): EAB pressure was slow to build from June, 2010 to June, 2013. Beginning in June and through August, 2013, significant differences in PCL occurred between trees treated with an annual BSD of Arena 50WDG (PCL = 13%) and the untreated controls (June, $F = 2.4$; $P = 0.04$ and August, $F = 2.3$; $P = 0.04$) (Table 6). The remaining treated trees had a slightly higher PCL of 15% to 19%. By August, 2014, all treated trees had significantly lower PCL (less than 23%) compared to untreated trees, which were all dead (PCL = 100%) (June, $F = 3.9$; $P < 0.001$ and August, $F = 8.3$; $P < 0.001$). Specifically, trees treated with an annual mid-June basal soil drench of Arena 50WDG, Arena 50WDG + Safari 20SG, an annual mid-June basal trunk spray of Arena 50WDG, or an annual mid-June basal broadcast application of Safari 2G, had significantly lower PCL (mean = 13%) compared to trees treated with a mid-June or mid-July basal soil drench of Safari 20SG (mean PCL = 20%) (Table 6).

Fermi Lab Village Green Ash Study (2008–2015): Our EAB trap tree monitoring program, implemented in May, 2008, indicated it took approximately three years for the EAB infestation to spread to the Fermi Lab Village study site, a distance of approximately 1.8 km. These observations are consistent with the rate of natural spread of EAB (Herms and McCullough 2014). PCL from 2008 to 2010 did not exceed 15% for all treated and untreated trees (Table 7). The 2011 field season appeared to be the tipping point, and coincided with when EAB was first detected in trap trees along the western edge of the study site. Beginning with the 2011 field season, treated trees had significantly lower PCL (mean less than 17%) compared to untreated control trees (PCL = 30%) ($F = 2.5$; $P < 0.02$) (Table 7). From 2012 until the end of the study in 2015, PCL for all treated trees declined and remained below 6%, while PCL for unprotected trees increased to 90% by 2013. All untreated trees were dead by 2015 (2012, $F = 4.6$; $P < 0.001$; 2013, $F = 51.6$; $P < 0.001$; 2014, $F = 52.4$; $P < 0.001$; 2015, $F = 49.2$; $P < 0.001$) (Table 7). In addition, numerous untreated, non-study trees growing in areas around the FLV site, were also dead.

Role of ash tree size in the efficacy of an imidacloprid basal soil drench. To evaluate the role of tree size, for treatment efficacy of a 1× rate of an annual mid-May imidacloprid basal soil drench application, treated and untreated green ash trees, at the Skokie and Homewood study sites were grouped separately for a regression analysis because both studies were started in 2007 and 2008, respectively; and the trees were in a similar condition (PCL equal to 7% and 6%, respectively) at the beginning of their respective studies. Regression analysis revealed that tree size had no significant effect on rates of decline for either untreated control trees ($F = 0.01$, $R^2 = 0.01$, $P = 0.95$) or trees treated with a 1× rate of an annual mid-May imidacloprid basal soil drench ($F = 1.71$, $R^2 = 0.10$, $P = 0.21$). Both smaller (less than 50 cm dbh) and larger (greater than 50 cm dbh) untreated control trees at the Homewood and Skokie study sites declined to a

Table 5. Evaluation of a single mid-May basal soil drench (BSD) of professional Merit 2F (imidacloprid 25%), or BATSC (imidacloprid 0.74% + clothianidin 0.37%), a single mid-May basal broadcast application (BBA) of BATSGF3 ((imidacloprid 0.55% + clothianidin 0.275% plus 2-1-1 fertilizer) or BATSGF4 (imidacloprid 1.1% plus 2-1-1 fertilizer), and a single mid-May BSD of BATSCF (imidacloprid 1.47% plus 2-1-1 fertilizer) all at the 2X rate for protection of green, white, and blue ash park and parkway trees at Riverside (RV), Hinsdale (HI), Naperville (NV), and Woodridge (WR), Illinois. Each treatment has 10 single tree replicates for the Riverside and Hinsdale green ash sites, five single tree replicates each for the Naperville and Woodridge white ash sites, and six single tree replicates for the Riverside blue ash study site.

TREATMENT One mid-May BSD or BBA at 2X application rate		Mean % canopy loss ratings ± SEM[1]							
		2012		2013		2014		2015	
	N[2]	June	August	June	August	June	August	June	August
Riverside (RV) green ash trees Mean dbh = 61 cm (range = 51–91 cm)									
Merit 2F (BSD)	10	20 ± 4.0a	24 ± 4.2a	20 ± 2.4ab	40 ± 6.9ab	32 ± 2.1a	13 ± 1.7a	30 ± 13.6a	18 ± 6.0a
BATSC (BSD)	10	25 ± 5.7a	25 ± 5.7a	15 ± 2.3a	35 ± 6.9ab	32 ± 2.5a	22 ± 1.7a	20 ± 13.1a	20 ± 5.7a
BATSGF1 (BBA)	10	19 ± 4.6a	24 ± 4.2a	14 ± 1.2a	33 ± 4.3ab	33 ± 6.9a	29 ± 7.1a	21 ± 8.4a	15 ± 2.2a
BATSGF4 (BBA)	10	20 ± 4.5a	17 ± 3.9a	14 ± 2.5a	26 ± 4.2a	31 ± 7.1a	20 ± 6.8a	10 ± 13.2a	20 ± 7.6a
BATSCF (BSD)	10	20 ± 3.8a	19 ± 3.7a	14 ± 2.5a	29 ± 4.4a	26 ± 8.4a	28 ± 8.5a	12 ± 9.7a	19 ± 3.3a
UTC	10	13 ± 5.5a	13 ± 5.5a	27 ± 4.6b	57 ± 9.5b	72 ± 4.4b	100 ± 0.0b	100 ± 0.0b	100 ± 0.0b
Significance:		NS[2]	NS	**F=8.7 P<0.001**	**F=6.2 P<0.001**	**F=3.3 P=0.015**	**F=32.9 P<0.001**	**F=31.2 P<0.001**	**F=47.8 P<0.001**
Hinsdale (HI) green ash trees Mean dbh = 51 cm (range = 46–91 cm)									
Merit 2F (BSD)	10	13 ± 2.1a	14 ± 2.0a	24 ± 4.0a	34 ± 2.4a	27 ± 5.6a	30 ± 5.8a	29 ± 3.5a	27 ± 3.1a
BATSC (BSD)	10	12 ± 1.7a	14 ± 1.9a	30 ± 5.7a	31 ± 4.9a	32 ± 7.1a	34 ± 7.8ab	37 ± 3.6ab	37 ± 3.6ab
BATSGF1 (BBA)	10	14 ± 2.2a	13 ± 2.1a	26 ± 4.6a	28 ± 4.4a	29 ± 7.8a	31 ± 8.6a	27 ± 2.1a	31 ± 1.9a
BATSGF4 (BBA)	10	22 ± 2.9a	23 ± 2.9a	33 ± 4.6a	38 ± 3.7a	34 ± 4.5a	39 ± 6.8ab	30 ± 3.5a	30 ± 2.7a
BATSCF (BSD)	10	12 ± 1.7a	16 ± 2.1a	28 ± 3.9a	29 ± 3.9a	37 ± 4.8a	39 ± 5.9ab	39 ± 6.6ab	41 ± 6.9ab
UTC	10	22 ± 2.9a	25 ± 3.1a	39 ± 10.1a	45 ± 5.5a	43 ± 6.2a	59 ± 7.8b	59 ± 11.9b	59 ± 11.9b
Significance:		NS[2]	NS	**NS**	**NS**	**NS P=0.04**	**F=11.4 P=0.03**	**F=3.0 P=0.03**	**F=3.3**

Riverside (RV) blue ash trees									
Mean dbh = 26 cm (range = 19–36 cm)									
Merit 2F (BSD)	6	9 ± 0.7a	6 ± 0.7a	4 ± 0.0a	4 ± 1.0a	3 ± 0.0a	4 ± 0.0a	7 ± 1.4a	7 ± 1.4a
BATSC (BSD)	6	10 ± 1.1a	8 ± 1.1a	7 ± 1.8a	9 ± 1.9a	3 ± 0.0a	4 ± 1.2a	9 ± 1.5a	9 ± 1.5a
BATSGF1 (BBA)	6	9 ± 1.1a	5 ± 1.1a	7 ± 1.1a	6 ± 0.7a	3 ± 0.7a	4 ± 0.8a	8 ± 1.45a	8 ± 1.4a
BATSGF4 (BBA)	6	8 ± 1.0a	2 ± 1.0a	5 ± 1.0a	6 ± 0.7a	2 ± 0.7a	3 ± 0.2a	6 ± 1.2a	6 ± 1.2a
BATSCF (BSD)	6	9 ± 0.0a	9 ± 0.0a	9 ± 0.7a	10 ± 0.8a	6 ± 0.7a	7 ± 0.8a	8 ± 1.7a	8 ± 1.7a
UTC	6	11 ± 2.0a	7 ± 1.1a	5 ± 0.7a	6 ± 0.7a	7 ± 1.0a	7 ± 0.8a	12 ± 2.2a	12 ± 2.2a
Significance:		**NS[2]**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Naperville (NV) white ash trees									
Mean dbh = 58 cm (range = 51–64 cm)									
Merit 2F (BSD)	5	4 ± 3.0a	4 ± 3.0a	8 ± 2.0a	9 ± 2.1a	17 ± 4.9a	16 ± 3.9a	19 ± 4.3a	19 ± 4.3a
BATSC (BSD)	5	6 ± 2.6a	7 ± 2.5a	10 ± 3.1a	9 ± 1.5a	8 ± 2.5a	10 ± 0.0a	23 ± 8.0a	23 ± 8.0a
BATSGF1 (BBA)	5	3 ± 3.1a	3 ± 3.1a	10 ± 3.1a	13 ± 3.6a	5 ± 4.0a	6 ± 3.9a	20 ± 0.0a	20 ± 0.0a
BATSGF4 (BBA)	5	9 ± 3.3a	9 ± 3.3a	21 ± 4.1a	18 ± 2.8a	10 ± 0.0a	15 ± 0.5a	17 ± 3.3a	17 ± 3.3a
BATSCF (BSD)	5	9 ± 1.5a	8 ± 1.7a	11 ± 3.3a	15 ± 3.5a	12 ± 5.0a	17 ± 4.2a	28 ± 4.8a	28 ± 4.8a
UTC	5	15 ± 5.0a	18 ± 5.1a	12 ± 1.7a	15 ± 5.0a	12 ± 2.4a	17 ± 3.6a	22 ± 8.0a	22 ± 8.0a
Significance:		**NS[2]**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Woodridge (WR) white ash trees									
Mean dbh = 37 cm (range = 25–48 cm)									
Merit 2F (BSD)	5	6 ± 0.7a	6 ± 0.7a	7 ± 2.0a	9 ± 1.0a	7 ± 2.0a	10 ± 0.0a	15 ± 1.4a	15 ± 1.4a
BATSC (BSD)	5	9 ± 1.1a	9 ± 1.1a	8 ± 1.9a	8 ± 1.9a	5 ± 0.0a	9 ± 1.2a	14 ± 2.5a	14 ± 2.5a
BATSGF1 (BBA)	5	9 ± 1.1a	9 ± 1.1a	9 ± 1.1a	12 ± 1.7a	6 ± 0.7a	7 ± 0.8a	11 ± 2.5a	11 ± 2.5a
BATSGF4 (BBA)	5	8 ± 1.0a	8 ± 1.0a	8 ± 1.9a	6 ± 0.7a	6 ± 0.7a	9 ± 1.2a	12 ± 7.2a	12 ± 7.2a
BATSCF (BSD)	5	10 ± 0.0a	10 ± 0.0a	6 ± 0.7a	7 ± 0.8a	6 ± 0.7a	7 ± 0.8a	12 ± 1.7a	12 ± 1.7a
UTC	5	7 ± 2.0a	7 ± 2.0a	6 ± 0.7a	6 ± 0.7a	7 ± 2.0a	7 ± 0.8a	17 ± 2.2a	17 ± 2.2a
Significance:		**NS[2]**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

[1]Means followed by the same letter are not significantly different (Dunn's test; $P<0.05$)
[2]N = number of single tree replicates per treatment rate
[3]NS = Not significant ($P<0.05$)

Table 6. Evaluation of a single mid-June basal soil drench (BSD) of Arena 50WDG (clothianidin 50%), Safari 20SG (dinotefuran 20%), or Safari 20SG + Arena 50WDG (dinotefuran 20% + clothianidin 50%), a single mid-July BSD of Safari 20SG (dinotefuran 20%), a single mid-June basal trunk spray (BTS) of Arena 50WDG (clothianidin 50%) or Safari 20SG (dinotefuran 20%), and a single mid-June basal broadcast application (BBA) of Safari 2G (dinotefuran 2%) for protection of green ash parkway trees at Glen Ellyn, Illinois (GE). Each treatment has seven single tree replicates.

TREATMENT Glen Ellyn (GE) green ash parkway trees Mean dbh = 41 cm (range = 28-48 cm)		**Mean % Canopy Loss Ratings ± SEM[1]**								
	N[2]	**June 2010**	**June 2011**	**August 2011**	**June 2012**	**August 2012**	**June 2013**	**August 2013**	**June 2014**	**August 2014**
Arena 50WDG (BSD)	7	4 ± 2.3a	6 ± 1.5a	12 ± 2.9a	5 ± 2.1a	12 ± 3.1a	13 ± 3.1a	12 ± 3.2a	13 ± 3.1a	13 ± 3.1a
Safari 20SG (BSD) (*mid-June application*)	7	5 ± 0.9a	20 ± 4.3a	17 ± 8.2a	12 ± 4.9a	27 ± 13.2a	19 ± 3.9ab	16 ± 4.0ab	20 ± 5.9a	18 ± 5.6b
Safari 20SG + Arena 50WDG (BSD)	7	6 ± 1.5a	11 ± 4.6a	18 ± 7.9a	10 ± 4.2a	13 ± 3.0a	16 ± 2.6ab	15 ± 0.0ab	17 ± 2.9a	16 ± 2.8a
Safari 20SG (BSD) (mid-July application)	7	6 ± 1.4a	6 ± 1.7a	13 ± 3.1a	17 ± 8.2a	21 ± 5.4a	17 ± 4.9ab	16 ± 2.6ab	18 ± 5.4a	22 ± 6.1b
Arena 50WDG (BTS)	7	5 ± 2.2a	7 ± 2.1a	11 ± 4.9a	6 ± 2.8a	16 ± 2.5a	16 ± 3.7ab	16 ± 3.7ab	17 ± 2.0a	10 ± 0.0a
Safari 20SG (BTS)	7	4 ± 1.7a	11 ± 4.9a	16 ± 2.5a	8 ± 2.6a	14 ± 3.0a	16 ± 2.8ab	16 ± 2.8ab	17 ± 2.4a	11 ± 4.9a
Safari 2G (BBA)	7	4 ± 3.8a	14 ± 3.3a	20 ± 4.3a	7 ± 4.1a	20 ± 4.6a	19 ± 3.9ab	17 ± 3.6ab	20 ± 4.7a	16 ± 2.7a
UTC	7	4 ± 2.4a	11 ± 4.6a	14 ± 3.2a	20 ± 10.1a	34 ± 12.1a	43 ± 12.5b	43 ± 12.5b	100 ± 0.0b	100 ± 0.0c
Significance:		**NS[3]**	**NS**	**NS**	**NS**	**NS**	**F=2.4 P=0.04**	**F=2.30 P=0.04**	**F=3.89 P<0.001**	**F=8.25 P<0.001**

[1]Means followed by the same letter are not significantly different (Dunn's test; P<0.05)
[2]N = number of single tree replicates per treatment rate
[3]NS = Not significant (P<0.05)

Table 7. Evaluation of a single mid-May trunk injection (TI) of Tree-age (emamectin benzoate 4%) for protection of green ash park and parkway trees at the Fermi Lab Village (FLV), Fermi National Accelerator Laboratory (FNAL), Batavia, Illinois. Each treatment has 10 single tree replicates.

TREATMENT Fermi Lab Village (FVL) green ash park and parkway trees Mean dbh=44 cm (range=38-50) for small trees Mean dbh=60 cm (range 50-70 cm) for large trees One single mid-May trunk injection of 4% emamectin benzoate (EB) in 2008 and again in mid-September, 2012		Mean % Canopy Loss Ratings ± SEM[1]							
	N[2]	2008	2009	2010	2011	2012[1]	2013	2014	2015
Tree-Age Quik-Jet-Small Trees (0.2 g a.i./2.54 cm dbh)	10	7 ± 1.9a	11 ± 3.1a	12 ± 3.1a	15 ± 0.0a	5 ± 0.0a	5 ± 0.0a	5 ± 0.0a	5 ± 0.0a
Tree-Age Tree IV-Small Trees (0.3 g a.i./2.54 cm dbh)	10	12 ± 1.1a	7 ± 0.8a	14 ± 2.9a	16 ± 2.8a	5 ± 0.0a	5 ± 0.0a	5 ± 0.0a	5 ± 0.0a
Tree-Age Quik-Jet-Large Trees (0.4 g a.i./2.54 cm dbh)	10	8 ± 1.8a	14 ± 2.5a	12 ± 2.7a	15 ± 0.0a	5 ± 0.0a	5 ± 0.0a	5 ± 0.0a	5 ± 0.0a
Tree-Age Tree IV-Large Trees (0.6 g a.i./2.54 cm dbh)	10	6 ± 1.8a	14 ± 3.5a	6 ± 1.3a	9 ± 1.9a	5 ± 0.0a	5 ± 0.0a	5 ± 0.0a	5 ± 0.0a
UTC	10	11 ± 5.5a	14 ± 4.1a	11 ± 2.2a	30 ± 0.0b	56 ± 5.7b	90 ± 3.6b	95 ± 3.2b	100 ± 0.0b
Significance:		**NS[2]**	**NS**	**NS**	**F=2.5 P<0.02**	**F=4.6 P<0.001**	**F=51.6 P<0.001**	**F=52.4 P<0.001**	**F=49.2 P<0.001**

[1]Means followed by the same letter are not significantly different (Dunn's test; P<0.05)
[2]N = number of single tree replicates per treatment rate
[3]NS = Not significant (P<0.05)

Table 8. Summary of percent phloem area utilized by EAB larvae, mean number of galleries/m², and mean number of adult exit holes/m² for branch samples taken from treated and untreated trees at the Aurora and Homewood study sites during the winter of 2011–2012.

BRANCH SAMPLING VARIABLE[1]	STUDY SITE				
	N	**Aurora[2]**	**N**	**Homewood[3]**	**Significance**
Mean % phloem area utilized for untreated trees	40	61 ± 6.2b	44	25 ± 3.0a	t = 5.6, P=0.005
Mean number of galleries/m² for untreated trees	40	268 ± 31.4b	44	64 ± 3.5a	t = 6.5, P=0.003
Mean number of exit holes/m² for untreated trees	40	179 ± 6.9b	44	16 ± 2.3a	t = 6.0, P=0.004

[1]Means followed by the same letter across rows are not significantly different (t-test, P<0.05)
[2]N equals a total of 40 branch samples taken for all remaining untreated trees
[3]N equals a total 44 branch samples taken for all remaining untreated trees

weakened condition and an unacceptable appearance (80% and 42%, respectively). Treated trees, at both sites, remained in excellent to good condition with 9% and 20% percent canopy loss for Homewood and Skokie trees, respectively (Tables 2 and 4).

Role of ash tree size, tree species, and tree size-species interaction on the efficacy of basal soil drenches of imidacloprid applied alone or in combination with clothianidin. A two-way ANOVA procedure was used to examine the role of tree size, species, and their interaction on the efficacy of all trees treated with an annual mid-May 2× application of professional Merit 2F and Bayer Advanced Tree and Shrub homeowner products (imidacloprid alone, and imidacloprid plus clothianidin) (refer to Table 1) for the smaller white ash (Woodridge), larger white ash (Naperville), larger green ash (Riverside, Hinsdale), and small blue ash (Riverside) trees. The white, green, and blue ash trees from the Woodridge, Riverside, Naperville, and Hinsdale study sites were grouped together because all four studies were initiated in 2012 were of same duration (2012–2015), and all the trees were in good to excellent condition (10 to 20% canopy loss) at the beginning of their respective studies. Results from the two-way ANOVA revealed that ash tree size ($F = 1.2$; $P = 0.30$), ash tree species ($F = 0.62$; $P = 0.43$), and, tree size- species interaction ($F = 0.9$; $P = 0.36$) were not significant for percent canopy loss.

Phloem utilization by EAB larvae at the Aurora, Homewood, and Fermi Lab Village Sites. A summary of phloem utilization by EAB larvae, mean number of total galleries per m², and mean number of exit holes per m² for untreated trees at the Aurora and Homewood study sites is presented in Table 8. Percent phloem utilization of remaining untreated Aurora green ash trees, by EAB larvae, was significantly greater ($T = 5.6$; $P = 0.005$), by over two times, compared with the Homewood site (61% versus 25%). Over four times as many galleries were constructed, per m² of branch surface area, on untreated trees at the Aurora site (268 versus 64 galleries) compared with untreated Homewood trees ($T = 6.5$; $P = 0.003$), and over 10 times as many exit holes per m² of branch surface area were counted on untreated Aurora study trees compared with untreated Homewood trees (179 versus 16 exit holes) ($T = 6.0$, $P = 0.004$). A regression comparing percent canopy loss with the number of branch galleries and adult EAB exit holes per m² of branch surface area, revealed a very strong relationship between percent canopy loss and the number of galleries/m² ($R^2 = 0.90$; $P < 0.001$) and adult EAB exit holes/m² ($R^2 = 0.88$; $P = 0.002$) accounting for 90% and 88% of the variation, respectively suggesting that EAB pressure was much higher at the Aurora site compared with the Homewood site by the end of the 2011 growing season.

Branch samples taken from remaining untreated trees at the Skokie site revealed 7% phloem utilization by EAB larvae, a mean of 24 larval galleries/m², and a mean of 10 adult exit holes per m² suggesting that EAB pressure was low and was very similar to the Homewood site.

While only one treated and two untreated study trees were sampled at the Fermi Lab Village site, the differences in percent phloem utilization, mean number of galleries/m^2, and mean number of exit holes/m^2 between treated and untreated trees were very apparent. Branch samples taken from the single tree treated with emamectin benzoate had 0% phloem utilized, no EAB larval galleries, and no adult EAB exit holes. In contrast, the two untreated trees had a mean larval phloem utilization of 50%, 130 galleries/m^2, and 90 exit holes/m^2.

Discussion

Neonicotinoid-class insecticides have been shown to be effective when applied as basal soil drenches and/or via soil injections for wood-boring and tunneling insect pests, and these products are available to homeowners as well as professional applicators, in part, due to their systemic action, and having shown effectiveness in protecting ash trees less than 38 cm dbh from EAB (Wang et al. 2005; Smitley et al. 2010 a,b, 2015; McCullough et al. 2011; Herms et al. 2014). However, only a limited number of studies have examined the efficacy of neonicotinoids for protection of ash trees larger than 38 cm dbh, and more specifically ash trees over 50 cm dbh (Smitley et al. 2010a, b, 2015; Bick et al. 2018; McCullough et al. 2019). In an effort to provide homeowners and professional practitioners with options for chemically protecting larger green and white ash trees from EAB, we evaluated various active ingredients and their combinations, at different rates, formulations, application methods and timing of neonicotinoid-class insecticides, and emamectin benzoate.

The authors recognize that PCL is a relative measure of insecticide efficacy, but in this study the very strong correlation between the number of galleries/m^2 and percent canopy loss supports the use of PCL as a reliable measure of insecticide efficacy. In addition, Flower et al. (2015) found the ash canopy condition rating system to be a proxy of EAB densities at the tree level, and that the canopy rating system was able to identify trees in the early stages of an EAB infestation with relatively low levels of EAB (less than 20% gallery cover or less than 40 EAB/m^2). Further, visual estimates of PCL are used in field studies to evaluate insecticide performance, phytotoxicity, and plant damage caused by wood-boring insect pests of woody plants (Ball and Simmons 1980; Anulewicz et al. 2007, 2008; Smitley et al. 2008, 2010 a,b, 2015; McCullough et al. 2011; Nielsen et al. 2011; Bick et al. 2018; Subburayalu and Syndor 2018).

There are many factors that may affect the efficacy and use of an insecticide for protecting ash trees from EAB, including but not limited to, EAB pressure, timing and method of application, overall tree health, related ash tree insect pests and diseases, soil moisture, and ash tree species composition. Here, we will briefly discuss the potential effects of EAB population pressure, ash species composition, and drought may have on the efficacy of chemical treatments, and the importance of recognizing and adjusting for these factors when formulating and implementing a comprehensive EAB management plan.

Efficacy of imidacloprid applied alone and imidacloprid in combination with clothianidin for the protection of ash trees from EAB

Smaller ash trees (less than 50 cm dbh). Collectively, all commercial and homeowner formulations, rates, and application timing of imidacloprid used alone or in combination with clothianidin provided good to excellent protection (PCL less than 17%) of Aurora and Homewood green ash, Woodridge white ash, and Riverside blue ash parkway trees. Further, there does not appear to be any added benefit to applying imidacloprid combined with clothianidin. Our findings are consistent with previous studies by McCullough et al. (2011), Tanis and McCullough (2012), Smitley et al. (2015), Bick et al. (2018) for trees with a similar dbh, and treated with similar active ingredients, combinations, timing, and rates of application. The lower level of protection of the basal broadcast application of BATSGF1 and basal soil drench of BATSC2X treatments at the Aurora study site is not clear. It is possible that the active ingredient of the granular formulation (i.e. BATSGF1) did not thoroughly leach from the granules, but was not investigated in this study. Another possible explanation could be EAB pressure. The much higher EAB pressure at the Aurora site, compared with the Homewood site, in conjunction with the 2012 drought may be partially responsible for the reduced protection of the basal broadcast application of BATSGF1 and basal soil drench of BATSC2X treatments at the Aurora study site. Additionally, the Homewood study was concluded, prior to the onset of the 2012 drought. These findings illustrate the importance of the role of soil moisture conditions in the uptake and distribution of protective chemicals, and of applying these chemical treatments well in advance of a building EAB infestation while trees are still healthy and before damage is very apparent. Failure to act can result in lack of effective EAB control and extensive loss of tree cover (Herms et al. 2019).

Larger ash trees (greater than 50 cm dbh). Taken together**,** all commercial and homeowner formulations, rates, application methods, and timing of imidacloprid used alone or in combination with clothianidin, applied annually at the 2× rate provided good to excellent protection of green and white ash park and parkway trees at the Riverside Hinsdale, Naperville, and Skokie study sites for trees with a mean dbh greater than 50 cm dbh; the only exception being the Hinsdale trees treated in mid-May at the 2× rate with basal soil drenches of BATSC and BATSCF. Interestingly, in this study, tree size (dbh) did not have any significant effect on the rate of decline of Homewood and Skokie untreated trees ($R^2 = 0.01$, $P = 0.95$) or trees treated ($R^2 = 0.10$, $P = 0.21$) with an annual 1× basal soil drench of imidacloprid. However, efficacy of the 1× imidacloprid basal soil drench did decrease for the larger treated Skokie trees (final PCL = 28%) probably because of the relationship between tree size (dbh), tree surface area, and phloem biomass ((LeGoff and Ottorini 1996, McCullough and Siegert 2007, Smitley et al. 2010b). Our findings are in contrast to a study by Smitley et al. (2010b), where it was found that canopy thinning was dependent on trees size (dbh) ($R^2 = 0.48$, $P < 0.002$) for trees receiving an annual basal soil drench of imidacloprid at the same rate and timing as in our study, and treated trees over 38 cm dbh declined to a weakened state and undesirable appearance (PCL of 35 to 80%) by the end of their study. In our study, both the smaller Homewood (mean dbh = 41 cm) and larger (mean dbh = 58 cm) Skokie treated trees remained in excellent to good condition, respectively. It is possible that the lower EAB pressure at the Skokie site may have afforded the larger trees the ability to fight off EAB allowing the 1× imidacloprid rate to still provide some level of EAB protection. These findings point to the need and importance of increasing treatment rates for larger trees, and illustrates the effect EAB pressure can have on insecticide treatment efficacy for both small and large trees. The reduced level of protection of the mid-May basal soil drenches of BATSC and BATSCF for the Hinsdale green ash trees is also unclear, but may be partially explained by the regional record-setting drought beginning in fall, 2011 and continuing through late summer, 2012. The overall 20% increase in percent canopy loss of treated green ash trees at the Hinsdale site in June, 2013, immediately following the 2012 drought, is consistent with studies by Smitley et al. (2015) which found an increase of 5% to 35% canopy loss following a 2008 spring and summer drought. A similar but delayed percent canopy loss drought response was observed by August, 2013 for similar sized Riverside green ash trees treated with the same products, application methods and timing. Local field observations by the senior author during the 2012 and mid to late 2013 growing seasons revealed common landscape and parkway tree species going into early fall color and leaf scorch along with premature leaf drop all indicating tree stress conditions suggesting that the failure of the basal soil drenches of BATSC and BATSCF, to protect the larger Hinsdale study trees, was probably due more to drought conditions than EAB pressure.

Further, there was also a differential tree recovery response following the 2012 drought between treated trees at both the Hinsdale and Riverside sites. While not investigated in this study, this differential response may be partially due to differences in available soil rooting volume, degree of precipitation runoff and/or infiltration, and related soil moisture levels between the two sites. The Riverside green ash trees were growing in a park setting in the Des Plaines River floodplain with better drained undisturbed soils, in contrast to the Hinsdale trees which were growing in an older residential area with narrow parkways containing typical compacted urban soils with limited soil volume. There was less local precipitation in May, 2012, coming in 11-day period, compared with 2.54 cm more rainfall in June, 2012, but in only four days (Illinois State Water Survey Climate Data, 2012). It is possible that less infiltration and more runoff may have occurred for trees growing in dry crusted soil conditions in the Hinsdale residential parkways compared with Riverside trees growing in a park setting with greater infiltration, less compaction, and less runoff, which may have contributed to greater plant stress reducing the trees ability to fight off the EAB (Larsson 1989, Craul 1999, Herms 2002, Huberty and Denno 2004, Gregory and Dukes 2006, Fahey et al. 2013). Cregg and Dix (2001) found that green ash trees planted in a downtown urban area experienced more drought stress and suffered higher damage from clearwing borers than did trees in a park-like campus. With the return of above-normal precipitation during the 2014 and 2015 growing seasons (Illinois State Water Survey, September 2014 and 2015), treated Riverside ash trees began to recover, but treated Hinsdale trees failed to recover. These aforementioned abiotic factors (i.e. soil conditions, rooting volume, precipitation, and water infiltration) may have affected the uptake and subsequent distribution of the insecticide treatments, resulting in a lower level of protection for the Hinsdale treated trees.

Susceptibility of ash species to EAB. All North American ash species are considered susceptible to EAB, but green ash and black ash (*F. nigra*) appear to be more highly preferred, followed by white ash and blue ash (Herms et al. 2019). Previous studies and field observations by the authors and tree care professionals all have indicated that EAB infestations and subsequent green ash tree mortality appears to progress more rapidly compared to white and blue ash (Anulewicz et al. 2007, 2008; Rebek et al. 2008; Tanis and McCullough 2012, 2015; Herms et al. 2014; Herms 2015; Robinette and McCullough 2019; Miller, F. unpublished). Interestingly, over a four-year study period, the PCL of untreated white ash trees at the Naperville, and Woodridge study sites, and untreated Riverside blue ash trees never exceeded 23%, 18%, and 13%, respectively even though adjacent unprotected, non-study green ash trees at all three study sites were dead or dying. However, in our study tree size, species and their interaction did not explain differences in percent canopy loss by treatments at these study sites. These apparent differences in host susceptibility, and the rate and degree of mortality among North American ash species are not clearly understood, and probably include mechanical and chemical host plant characteristics. For example, differences in EAB host susceptibility may be related to differences in host volatiles, nutritional, and defensive compounds (Eyles et al. 2007; Chen and Poland 2009, 2010; Chen et al. 2011, 2012; Martinson et al. 2014; Herms 2015; Poland et al. 2015; Showalter et al. 2018). Additionally, initial and building EAB pressure, combining protective insecticides with ash tree population reduction and sanitation (i.e. "culling the herd" and tree removals) (McCullough and Mercader 2012, Lewis and Turcotte 2015, Rutkowski and Mitz 2017, McCullough et al. 2019) and biological control (Loerch and Cameron 1984, Anulewicz et al. 2008, Dirr 2009, Marshall et al. 2013, Duan et al. 2014, Bauer et al. 2015, Wang et al. 2016, Miller and Gould 2018) may also be contributing factors affecting ash EAB susceptibility and survival. Regardless of the factor(s) responsible for this differential mortality rate observed between green, white, and blue ash trees, the apparently less susceptible white and blue ash to EAB have the potential to impact EAB management decision-making processes, particularly for communities late to apply protective chemical treatments or with limited tree care budgets. Given a choice, some tree care managers are opting to protect existing white and blue ash trees and their cultivars over green ash trees (Dirr 2009, author's personal communication with green industry professionals). The more desirable growth habit, urban tolerance, and brilliant fall color of white ash, and drought tolerance and dark green leaves of blue ash are probably important factors in their preference and decision-making (Schlesinger 1990, Griffith 1991, Dirr 2009).

Efficacy of dinotefuran, clothianidin, and dinotefuran combined with clothianidin for protection of ash trees from EAB. In the single Glen Ellyn study, dinotefuran and clothianidin used alone, and in combination, were equally and very effective in protecting ash trees up to 50 cm dbh (PCL ratings less than 18%). There does not appear to be any significant additive effect by combining dinotefuran with clothianidin. These same active ingredients were as effective as imidacloprid used alone or when imidacloprid is combined with clothianidin for protecting similar size ash trees (PCL ratings of 10% to 14%).

Interestingly, the treated Glen Ellyn green ash trees did not show any significant effects from the 2012 drought. It should be noted, however, that the trees at the Glen Ellyn site had been treated for two years prior to the 2012 drought. Further, dinotefuran (Safari) is much more water soluble than imidacloprid and is able to be taken up and distributed faster in the tree compared with imidacloprid, allowing for dinotefuran to quickly target EAB larval feeding particularly when applied later in the growing season (Tattar et al. 1998; USEPA. U.S. Environmental Protection Agency 2004, 2014; Extoxnet Extension Toxicology Network 2010; Bryne et al. 2012, 2014; Nix et al. 2013; Bonmatin et al. 2015; Mach et al. 2018). This provides for greater flexibility for treating trees once an infestation has been identified, even during drought conditions. However, one disadvantage is that dinotefuran has a shorter residual efficacy compared to imidacloprid or emamectin benzoate.

Scheduling of applications within a given growing season is also important. In our studies, the single July basal soil drench of dinotefuran was equally effective in protecting trees as the June application, and is consistent with previous studies by McCullough et al. (2011, 2019) and Smitley et al. (2015). In situations where an EAB infestation is not discovered until later in the growing season (i.e. mid-June to mid-July), and/or if treatments are otherwise delayed, dinotefuran or clothianidin alone, and/or in combination can be an effective option for protecting ash trees up to 50 cm dbh.

Effectiveness of emamectin benzoate for protection of ash trees from EAB. After eight years, it is evident that all rates, application timing, and trunk injection application methods of professional Tree-Age (emamectin benzoate) is highly effective (PCL less than 6%) in protecting green ash trees up to 55 cm dbh, even during a severe drought. Our findings are comparable to studies conducted by Anulewicz et al. (2007, 2008), Bick et al. (2018), Lewis and Turcotte (2015), McCullough et al. (2011, 2019), and Smitley et al. (2010 a, b). Additionally, in an unrelated ash Naperville–Bolingbrook, Illinois tree preservation study, biennial trunk injection applications of Tree-Age (emamectin benzoate) is currently providing excellent protection of similar size green and white ash trees (Rutkowski and Mitz 2017, Miller and Gould 2018).

In summary, while some ash trees have recovered from as much as 60% canopy loss (Smitley et al. 2007), members of the green industry generally consider up to 30% canopy loss to be acceptable level of damage when evaluating for treatment efficacy and whether to remove and replace a tree (Bick et al. 2018). The vast majority of the treatments evaluated in this study provided good to excellent control (percent canopy loss less than 30%), with the exception of BATSGF1and BATSC2X at the Aurora site, and BATSCF at the Hinsdale site. Annual applications of imidacloprid applied alone at 0.57 g active ingredient (a.i.)/2.54 cm dbh or greater, clothianidin and dinotefuran applied alone at 0.93 g a.i./2.54 cm dbh or greater, imidacloprid + clothianidin at 0.57 g a.i. + 0.28 g a.i.2.54 cm dbh or greater, or dinotefuran + clothiandin applied annually at 0.47 g a.i. + 0.46 g a.i./2.54 cm dbh or greater provided good to excellent protection of green, white, and blue ash trees up to 61cm dbh. Biennial trunk injections of emamectin benzoate applied at 0.2 to 0.6 g a.i./2.54 cm dbh provided good to excellent protection of green ash trees with a mean dbh of 61 cm and, may provide extended protection under moderate to heavy EAB pressure even during a record-setting drought. Tree care practitioners and homeowners have a variety of available options for the timing and application of protective chemicals including basal soil drenches, basal broadcast applications, basal trunk sprays, and soil and trunk injections for protection of their ash tree resource from the EAB. It is important to remember that not all ash tree species are equally susceptible to EAB, and studies are showing, that while still susceptible, decline and death in white and blue ash is slower, and in some cases they may actually survive an EAB infestation (Tanis and McCullough 2012, Robinett and McCullough 2019). Further, professionals and homeowners should recognize the impact that abiotic factors (i.e. drought), and soil rooting volumes may have on the uptake and distribution of protective systemic chemicals, specifically where EAB infestations have been initially confirmed. Diligent inspection of susceptible ash trees, proper selection, timing and application of insecticidal treatments, public awareness and education, and communication among all concerned parties are all critical to implementing an effective EAB management plan for protection of our valuable urban forest resource.

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