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Urban Naturalization for Green Spaces Using Soil Tillage, Herbicide Application, Compost Amendment and Native Vegetation

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Abstract: Naturalization is a new and promising ecological approach to green space development for urban environments, although knowledge is sparse on techniques to implement it. We evaluated naturalization of eight native trees and shrubs, with site preparation (tillage, herbicide) and soil amendment (compost rates) treatment combinations at six sites in the city of Edmonton, Alberta, Canada. Soil texture improved with all compost rates, and acidity, electrical conductivity and total carbon increased, especially with 100% compost. Soil nutrients generally increased with compost then declined within a year. Plant species with highest potential for use in urban green spaces were *Picea glauca*, *Symphoricarpos albus* and *Rosa acicularis*. Herbicide was the most influential site preparation treatment, positively increasing survival and growth of planted woody species, while negatively lowering non-native species cover and increasing noxious weed cover. Soil amendment with compost influenced cover not species richness, with high compost amendment reducing vegetation cover across sites, and increasing individual plant size. This study suggests amendment of soil with compost and appropriate site preparation can positively influence naturalization of these woody species for urban green spaces.

Keywords: compost; green spaces; herbicide application; native species; plant community; site preparation; soil amendment; urban naturalization

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1. Introduction

Urban environments have consistently grown in importance as biomes for the human race. In 1950, urban dwellers comprised 29.4% of the world population, which increased to 51.6% by 2010 and is projected to increase to 67.2% by 2050 [1]. This projection increased the complexity of providing urban ecosystem benefits for nature and people in cities [2]. Urban green spaces (public and private gardens, parks, other green infrastructure) provide a variety of ecosystem services, including biodiversity, microclimate mitigation and storm water management [3–6] and aesthetic value for socio-cultural aspects (human health and wellbeing) [7,8]. Therefore, appropriate management of urban green spaces is necessary to support ecological processes, enhance habitat quality [9] and sustain urban greening strategies [10]. Although years of research have been focused on land reclamation, ecological restoration and plant establishment, knowledge is sparse on how to reintegrate native ecological components into urban green spaces.

Naturalization is a process of ecological restoration that involves returning an altered or degraded site to a more natural condition through use of trees, shrubs and forbs that are native to the area [11]. In urban naturalization native ecological components are integrated in green areas through natural processes of plant colonization and growth, facilitating the landscape to return to a more natural state [12,13]. A successful naturalization strategy can significantly reduce city management costs, promote preservation of local species, restore environmental services and encourage more community members to embrace naturalization as a desirable strategy to follow [12,14]. Urban naturalization historically focused on planting trees to restore urban forests. However, naturalization can occur in urban grassland and wetland areas. It requires careful selection of plant species for development of an appropriate plant community [15]. Usually, native plant species are used, although in many urban centres, local cultivars and non-native species have been included [16,17].

Planted garden flora in cities frequently contain cultivated non-native species [18,19] which originated outside of the natural region; a significant pathway for non-native species to be introduced worldwide (e.g., Germany [20], Czech Republic [21], UK [22], USA [23], Australia [24], South Africa [25]). Many of these non-native species escape and establish outside of the gardens without human assistance and become problematic invaders with negative impacts on native biodiversity [13,18,26,27]. Eradication of non-native species is difficult and expensive, making prevention of new non-native species invasions by naturalizations of native species an important process.

Naturalization can address inherent soil limitations such as compaction, low organic matter and low microbial activity [15,28]. Compacted soils can prevent or restrict root growth and therefore successful plant establishment and long-term development [29]. Naturalization can reduce soil compaction, through root expansion, increased biological activity and frost heave [30], subsequently increasing infiltration [12] and percolation. Naturalized sites add organic material via decomposing retained leaf litter and woody debris, which can increase soil water availability [31] and nutrient availability for plants. Alternatively, these soil limitations can be reduced as part of the naturalization process through use of soil amendments.

Scientific research on methods to achieve naturalization of urban parklands with native woody species is lacking, and results of naturalization efforts to date have been inconsistent. Many of these sites require reclamation to address soil issues and all require revegetation to facilitate development into a naturalized ecological community. The objective of this study was to evaluate urban naturalization in green spaces using eight native tree and shrub species, site preparation techniques and soil amendment. Site preparation and soil amendment were expected to impact plant species survival and growth, and plant community composition, species richness and cover. Based on this study, we can predict which combinations of plant species, soil preparation techniques and amendments have the greatest potential to naturalize urban green spaces.

2. Materials and Methods

2.1. Study Area and Experimental Design

The study was conducted in six urban green areas in the City of Edmonton, Alberta, Canada, (53°34′19″ N and 113°31′10″ W). Elevation is 671.4 m above sea level. Mean annual temperature is 4.2 °C; mean growing season temperature from May to October is 13.0 °C, and winter temperature from November to April is −4.6 °C. Mean annual precipitation is 348 mm, with greatest amounts from June to October (284.4 mm). Snowfall mean is 122 to 124 cm from October to May [32].

The experiment used a complete randomized design with three replicates in each of six sites. Each experimental plot was 10 m × 10 m, divided into sixteen 2.5 m × 2.5 m subplots, covering an area of 6.25 m^2. Site preparation treatments were randomly assigned vertically to plots in strips, with amendment treatments applied randomly within each strip. Thus, there were 4 site preparation treatments × 4 amendment treatments × 3 replicates for a total of 48 plots in each of six sites to assess tree and shrub response.

2.2. Site Preparation and Soil Amendment Treatments

Four site preparation techniques were used to remove existing vegetation, which consisted of lawn grass and some common annual weeds. Treatments were soil tilling, foliar herbicide application, a tilling plus herbicide and no site preparation (control). Soil was tilled in June 2014 to a 15 cm depth with a rear tined, hydraulic drive, rototiller, first in one direction, then crossed perpendicularly. Roundup Transorb™ foliar herbicide was applied as a 1% solution (540 g/L glyphosate) in June 2014, 2 weeks prior to site tillage. Application of glyphosate herbicide is predominantly used for controlling weeds in North America due to its effectiveness, non-selective nature, little or no soil residue and relatively low cost. However, the toxicity and environmental safety of glyphosate has been questioned and many agencies prefer an alternative. Some alternatives to glyphosate include other chemicals (Diquat (Reward™), pelargonic acid (Scythe™), glufosinate (Finale™)), manual removal or flame, steam or hot foam weeding.

Four soil amendment treatments were 100% compost, 50% topsoil and 50% compost, 80% topsoil and 20% compost, and no compost or topsoil (control). Compost was 80% compost and 20% wood chips by volume, a standard mix used by the City of Edmonton. Topsoil was Ah horizon from a development on previous agricultural land. Topsoil and compost were mixed in their treatment proportions, then applied using a mini steer loader. Amendment mixes were added to the surface of each subplot and spread by hand with shovels to a 15 cm deep layer.

2.3. Planting and Plot Management

Four native trees *Picea glauca* Moench Voss (white spruce), *Populus tremuloides* Michx (trembling aspen), *Populus balsamifera* L. (balsam poplar) and *Prunus virginiana* L. (chokecherry); and four native shrubs *Rosa acicularis* Lindl. (wild rose), *Symphoricarpos albus* L. (snowberry), *Viburnum trilobum* L. (highbush cranberry) and *Salix exigua* Nutt (coyote willow) were selected for urban naturalization. These plant species were from the same geographic location around Edmonton, thus with greater ecological adaptability for establishment. All planting stocks were procured from the City of Edmonton nursery and planted in the first 2 weeks of July 2014. At each site, each treatment subplot was planted with one species of each tree and each shrub (total 8 species = 4 trees and 4 shrubs) with equal spacing and a minimum of 15 cm from the subplot edge. There were 128 plants in each plot (replicate), 384 plants at each site and overall, 2304 trees and shrubs in six sites.

Plants were watered, 24 to 48 h post-planting; then every 2 to 3 days for the next 2 weeks, twice per week for the next 4 weeks, then once per week until end of the growing season. The site was managed for weed species as needed to meet City of Edmonton standards. All noxious weeds were hand pulled inside research plots; non-noxious weeds located within 10 cm of planted seedlings were hand pulled. Manual weeding was conducted within 2 m from the edge of research plots as a weed control buffer zone.

2.4. Vegetation Assessments

Planted tree and shrub health assessments were conducted in July and August 2014 and 2015. A five-category scale was used to assess plant health; with 1: healthy, 90 to 100% green, no signs of water stress, pests or diseases; 2: stressed, fair health, 50 to 89% green, some visible damage; 3: severely stressed, less than 49% green, clear signs of leaf chlorosis or necrosis; 4: dead, no green; 5: not found (plants died or removed by vandalism). Height and diameter (ground level) of each planted tree and shrub were measured in both years to estimate growth response.

Vegetation community assessments were conducted during the second week of August 2014 and 2015. In each subplot three randomly located 0.1 m^2 quadrats (total 144 quadrats at each site) were established to assess percent ocular cover of live vegetation, bare ground and litter. Live vegetation was assessed in more detail on an individual species basis to determine percent cover by species and species richness by counting the number of species found in each treatment. At each site, outside plot vegetation assessments were conducted on three permanent 10 m long transects to determine potential sources of invasion to the research plots. Transects were 3 m apart from the research plots in parallel to one of the borderlines of the plot. Transects were located to avoid established woody vegetation. Five 0.1 m^2 permanent quadrats were assessed on each vegetation transect.

2.5. Soils Sampling and Analyses

Soil was sampled in July 2014 and 2015 at each of the six sites in untilled locations to determine original soil conditions and changes with treatments. One sample from each amended treatment in each plot was collected using 15 cm augers (12 soil samples per site). Samples were composited by treatment by site, put into Ziploc plastic bags and sent to a commercial laboratory for analyses. Inorganic and organic carbon were determined by carbon dioxide loss [33] and total carbon by combustion [34]. Cation exchange capacity was determined through ammonium acetate extraction [35]. Chloride in saturated paste was determined colorimetrically by an auto-analyzer [36], and mercury spectrochemically (EPA 200.2/245.1). Metals were determined by acid digestion and inductively coupled plasma mass spectrometry (EPA 200.2). Total nitrogen was determined by combustion [37], available ammonium nitrogen by potassium chloride extraction and available nitrate nitrogen colorimetrically in calcium chloride solution [38]. Available phosphorus and potassium were determined by modified Kelowna process [39]. Sodium adsorption ratio was calculated, and calcium, magnesium, sodium, potassium and sulfate were determined in saturated paste by inductively coupled plasma [40]. Particle size (sand, silt, clay) was determined by pipette after removal of organic matter and carbonate [41]. Electrical conductivity and pH were determined in saturated paste by meters [4].

2.6. Statistical Analyses

All statistical analyses were conducted using R version 4.0.3 [42]. In most cases, data from the last monitoring date in 2015 were statistically analyzed to evaluate overall performance of species at the end of the experiment. Chi-square analysis was used to identify effects of site preparation and soil amendment treatments on species survival using plant health data. Plant variable (height and stem diameter change) response to site preparation and amendment were analyzed with an unbalanced two-way analysis of variance (ANOVA) with interactions. Shapiro–Wilk test was used for normality of distribution, and Levene's test for homogeneity of variance assessments. ANOVA tables were obtained using type III sum of squares to compensate for unbalanced data structure and least-square means calculations to avoid misleading mean values. For significant factors, an HSD Tukey's test was applied for pairwise comparison. Significance level for all analysis was $\alpha = 0.05$.

3. Results

3.1. Soil Response to Treatments

Unamended soil texture was generally clay loam to clay to silty clay loam, (mean clay 38%, silt 39%, sand 23%). With compost amendment, soil texture was generally loam (sand 45–49%, silt 30–32%, clay 19–23%) with improved properties for plant growth.

Soil pH was slightly acidic (mean 6.5), with increased acidity with 100% compost (mean 5.6) (Table 1). Electrical conductivity increased with percent compost, generally declining a year after compost application. Values were higher than desired with 100% compost amendment at 5.6, but declined to 2.5 within a year. Sodium adsorption ratio was very low in all treatments (mean 0.5), although at levels posing no issues for vegetation. Total carbon generally declined slightly within a year; mean 5.1% in year 1 to 4.6% in year 2 for all treatments; except 100% compost which was 19.4% dropping to 17.6% (Table 1). Soil nutrients generally increased with compost application, then declined within a year, being highest in both years with 100% compost. Nutrients were generally highest in the year of amendment, declining or staying steady within a year.

Table 1. Mean (±SE) soil properties by soil amendment treatments. Different letters indicate significant differences among amendment treatments in individual years at $\alpha = 0.05$. EC= Electrical Conductivity, SAR = Sodium Adsorption Ratio, TOC = Total Organic Carbon, CE ation Exchange Capacity.

Properties	0% Compost		20% Compost		50% Compost		100% Compost	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
pH	6.6(0.1)	6.8 (0.1)	6.3(0.2)	6.6(0.1)	6.3(0.1)	6.1(0.1)	5.5(0.2)	5.8(0.1)
EC (dS m^{-1})	0.6(0.1)c	0.7(0.0)y	2.6(0.5)b	1.7(0.3)x	4.3(0.4)a	2.3(0.4)x	5.6(0.4)a	2.5(0.4)x
SAR	0.5(0.1)	0.6 (0.1)	0.4(0.0)	0.4(0.1)	0.5(0.0)	0.4(0.0)	0.5(0.1)	0.3(0.0)
Total Carbon (%)	6.0(0.4)b	4.2 (0.3)y	4.1(0.7)b	3.6(0.5)y	5.3(0.3)b	6.0(1.2)y	19.4(0.5)a	17.6(1.4)x
TOC (%)	6.0(0.4)b	4.1 (0.3)y	4.1(0.7)b	3.5(0.5)y	5.3(0.3)b	6.0(1.2)y	19.3(0.5)a	17.4(1.4)x
Total Nitrogen (%)	0.5(0.0)b	0.4 (0.0)y	0.3(0.1)b	0.4(0.1)y	0.4(0.0)b	0.5(0.1)y	1.5(0.0)a	1.4(0.1)x
Ammonium (mgL^{-1})	10.7(1.4)b	6.6 (2.5)y	10.1(5.1)b	2.1(0.3)y	11.7(2.1)b	3.0(0.6)y	75.7(11.2)a	17.3(7.4)x
Nitrate (mgL^{-1})	25.8(3.3)d	12.9 (2.1)y	87.0(23.2)c	128.0(105.1)x	175.6(31.8)b	35.6(10)y	612.8(109.3)a	134.1(62.0)x
Phosphate (mgL^{-1})	52.7(12.1)c	34.9(6.8)z	405.3(145)b	213.0(11.2)y	526.2(22.4)b	554.0(89.8)x	2801.7(109.3)a	1615.0(173.2)w
Potassium (mgL^{-1})	722.0(67.4)b	544.5 (63.8)x	192.0(11.9)d	187.3(12.1)z	324.7(9.0)c	385.5(52.3)y	1280.0(48.6)a	1080.8(100.8)w
Sulfate (mgL^{-1})	14.0(2.2)d	20.1(3.8)z	123.0(23.6)c	69.4(23.9)y	318.7(32.4)b	131.8(41.1)y	1253.7(135.7)a	524.1(141.1)x
Calcium (mgL^{-1})	58.5(3.9)d	87.2 (5.2)y	311.1(53.1)c	269.7(48.2)x	549.8(75.7)b	360.0(61.0)x	1112.5(145.4)a	364.8(66.3)x
CEC (meq 100 g^{-1})	39.1(1.5)b	40.3 (5.2)y	27.4(4.0)b	31.2(5.0)y	33.2(4.9)bc	37.1(5.7)y	60.8(2.2)a	61.4(4.2)a
Chloride (mgL^{-1})	26.3(1.8)c	23.7(1.3)	25.6(5.0)c	29.2(5.7)	44.4(7.7)b	36.2(6.9)	95.3(16.5)a	26.2(3.1)
Copper (mgL^{-1})	21.7(0.5)c	1.1 (0.1)z	31.8(3.5)c	2.4(0.4)y	61.3(5.9)b	7.2(1.9)y	316.5(5.9)a	38.4(2.7)x
Magnesium (mgL^{-1})	16.2(1.2)d	22.0 (1.6)z	67.5(12.1)c	59.9(11.8)y	142.3(20.4)b	103.2(21.2)x	510.2(20.4)a	144.8(32.2)x
Sodium (mgL^{-1})	15.2(2.8)c	22.9 (5.8)y	26.4(4.1)c	28.5(5.8)x	42.9(6.4)b	30.5(4.6)x	97.8(15)a	28.2(4.1)x
Zinc (mgL^{-1})	91.2(2.9)c	6.0 (0.7)z	83.7(10.3)c	10.1(1.7)z	132.0(10.9)b	25.7(6.7)y	562.2(19.5)a	111.8(6.9)x

3.2. *Plant Survival Response to Treatments*

Regardless of site preparation and soil treatment, top surviving and performing tree and shrub species were *Picea glauca* and *Symphoricarpos albus*, followed by *Rosa acicularis*, which had greatest numbers in the two healthiest categories (Figures 1 and 2). Among tree species, mortality was greatest with *Populus tremuloides* and *Populus balsamifera*, and lowest with *Picea glauca* (Figure 1). Among shrub species, mortality was greatest with *Salix exigua* and *Viburnum trilobum*, and lowest with *Symphoricarpos albus*, followed by *Rosa acicularis* (Figure 2).

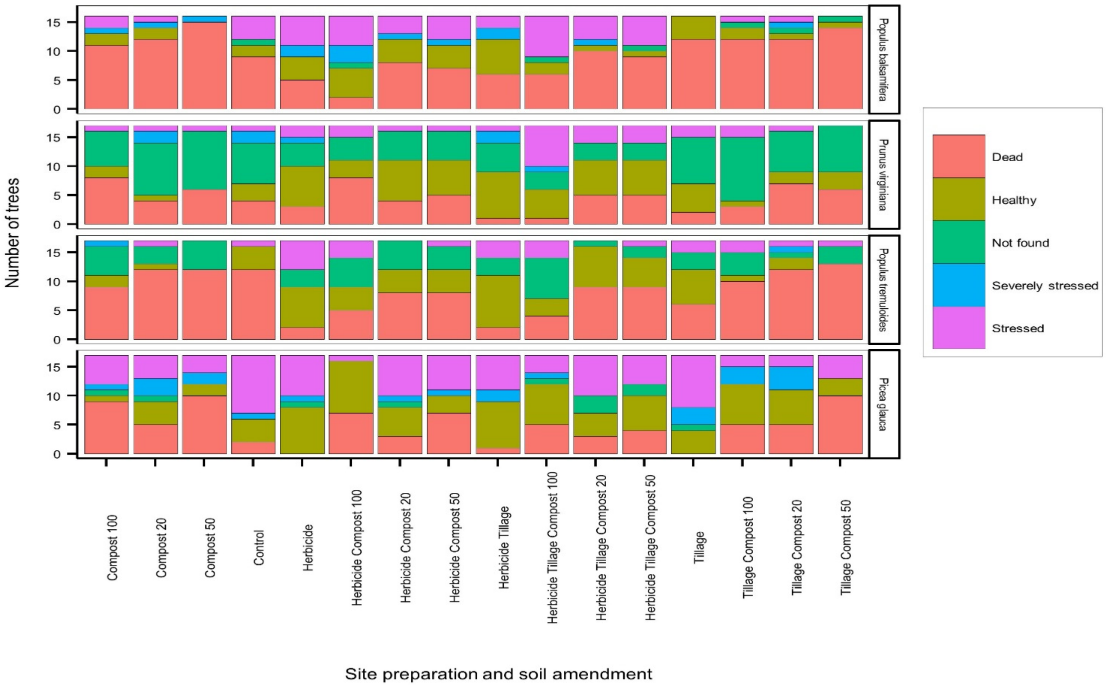

Figure 1. Number of individual tree species by health categories based on site preparations and soil amendments.

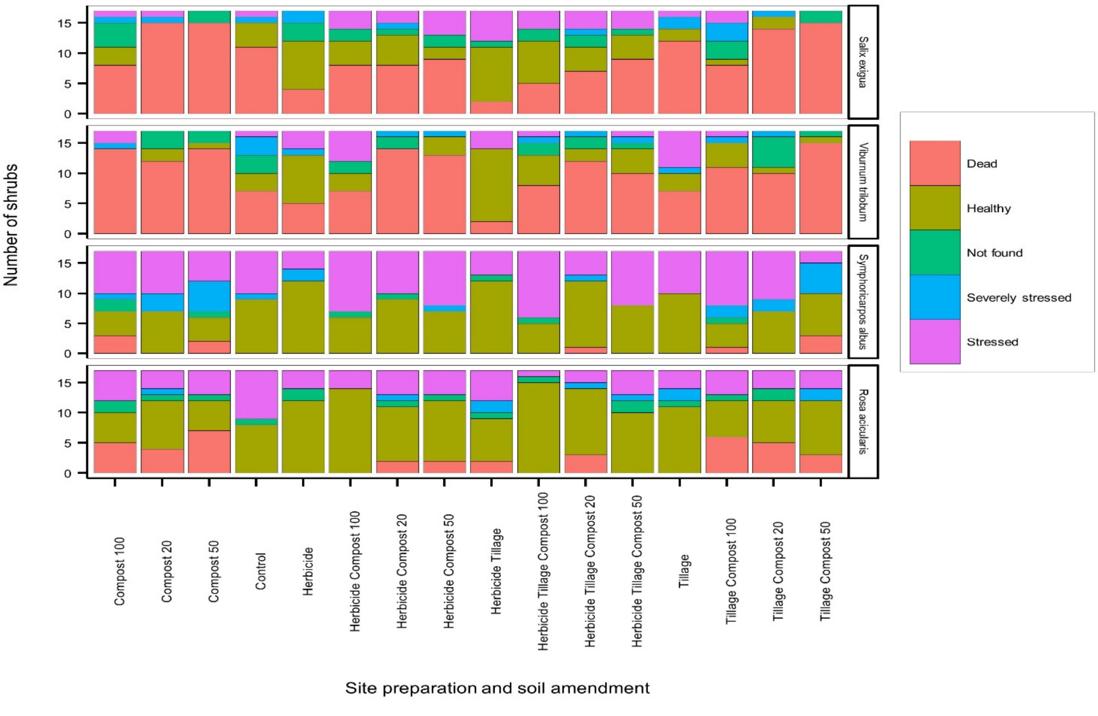

Figure 2. Number of individual shrub species by health categories based on site preparations and soil amendments.

Interaction between site preparation and soil amendment was not significant, thus further analyses were conducted using soil amendment and site preparation. When soil amendment and site preparation were considered individually, mortality of tree and shrub species varied. *Populus balsamifera* and *Populus tremuloides* mortality was lowest with herbicide alone and greatest with tillage alone and no site preparation. *Prunus virginiana* and *Salix exigua* mortality was lowest with herbicide plus tillage (Figure 3a,b). Although *Populus balsamifera*, *Prunus virginiana*, *Symphoricarpos albus* and *Rosa acicularis* mortality did not respond significantly to soil amendments, *Picea glauca* and *Viburnum trilobum* mortality was significantly lowest with no amendment and greatest with 50% compost amendment (Figure 3c,d).

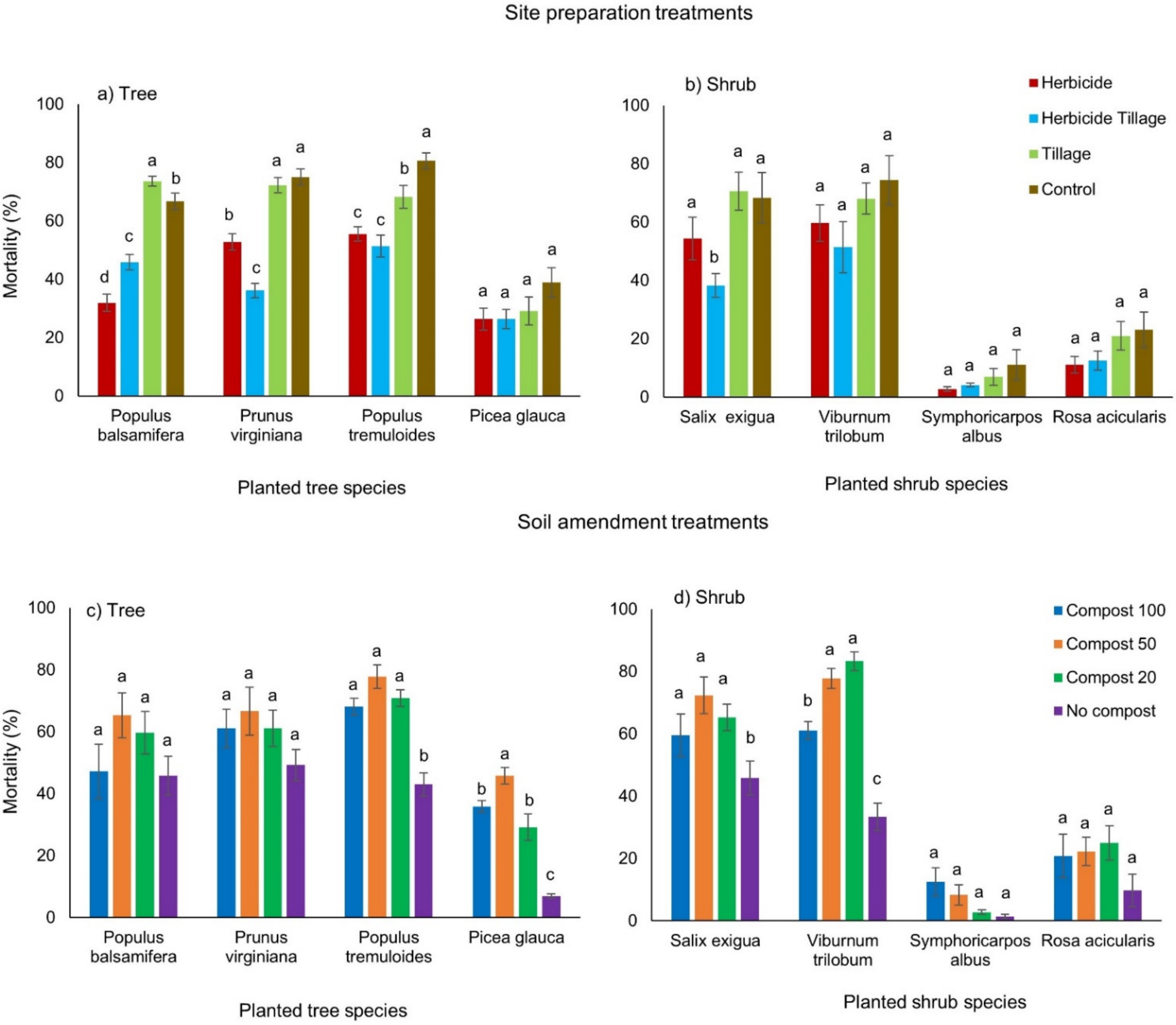

Figure 3. (**a**–**d**) Mean (±SE) mortality percent of individual tree and shrub by site preparations and soil amendments. Different letters within species indicated significance difference at α = 0.05.

Plant mortality by species varied with time and site. In year 1, *Prunus virginiana* had greatest mortality (14.6%) followed by *Salix exigua* (12.9%) in June, *Prunus virginiana* (10.4%) in August. By June of year 2 mortality increased for all tree and shrub species and kept rising until August of that year. At the end of the experiment, mortality was highest for *Populus balsamifera* (59.7%) and *Viburnum trilobum* (59.7%), followed by *Salix exigua* (53.5%)

and *Populus tremuloides* (47.2%) and lowest for *Symphoricarpos albus* (4.9%), followed by *Rosa acicularis* (14.2%) and *Picea glauca* (27.7%).

3.3. Effects on Tree and Shrub Height and Diameter

Site preparation treatments had a significant effect on height change for all tree species except *Populus balsamifera* and *Prunus viginiana*, and all shrub species except *Viburnum trilobum*. Soil amendment had a significant effect only on *Picea glauca* and *Symphoricarpos albus*. Height changes of tree species *Populus tremuloides*, *Picea glauca* and *Salix exigua* were significantly greatest with herbicide plus tillage and lowest with no site preparation treatment (Table 2). Similarly, significant effects on height change for *Symphoricarpos albus* and *Rosa acicularis* were with herbicide plus tillage. Treatment with 100% compost had the greatest height change for both of these species, whereas the lowest was with no amendment treatment (Table 2).

Site preparation treatments significantly affected tree stem diameter changes in *Populus balsamifera*, *Populus tremuloides* and *Picea glauca*, with greatest diameter change in herbicide plus tillage for *Picea glauca* and *Populus tremuloides* (Table 2). Greatest diameter change was with herbicide alone and lowest with tillage alone for *Populus balsamifera* (Table 2). Among shrub species, *Rosa acicularis* and *Symphoricarpos albus* stem diameter change was significantly lowest with tillage and no site preparation treatment and greatest with herbicide and herbicide plus tillage. Among soil amendment treatments, mean stem diameter change was highest with 100% compost and lowest with 50% compost for *Populus tremuloides* and *Picea glauca* (Table 2). For all four shrub species, stem diameter change was not significant with any soil amendment treatments.

3.4. Species Cover and Richness

Significant site preparation effects on cover of non-native ($p < 0.001$) and noxious ($p < 0.001$) species were observed, whereas soil amendment had only a significant effect on noxious ($p = 0.004$) species cover. Although vegetation cover per plant category varied with treatments, non-native species composed the majority of vegetation cover across all site preparation and amendment treatments followed by noxious and native species (Figure 4a). Non-native species cover was greater with no soil amendment treatment than with amendment and lower with herbicide than without herbicide (Figure 4a). Native species cover was greatest with 20% compost, whereas noxious species were generally greater in treatments with herbicide. Further pairwise comparison indicated that non-native species cover was significantly greater with herbicide than without herbicide. The opposite trend was found for noxious species cover, which was significantly greater with herbicide. Amendment application only had a significant effect on noxious species cover, with significantly greater cover without amendment than with 100% compost.

A total of 37 plant species other than planted trees and shrubs were identified across the plots, 26 non-native, 6 native and 5 noxious species. *Chenopodium album* L. (Lamb's quarters), *Elymus repens* (L.) Gould (couch grass) and *Poa pratensis* L. (Kentucky bluegrass) were found at all sites. *Bromus inermis* Leyss. (smooth brome grass), *Polygonum convolvulus* L. (wild buckwheat), *Thlaspi arvense* L. (stink weed), *Sonchus arvensis* L. (sow thistle) and *Tripleurospermum perforatum* (M rat) M. Lainz (scentless chamomile) were found at five out of six sites. Overall species richness did not differ by site preparation and soil amendment treatments, although non-native species had significantly greater ($p < 0.001$) richness than other groups. Highest non-native species richness was with herbicide plus tillage without soil amendment, whereas native species were completely absent with 100% compost, and were low in all other treatments (Figure 4b). Noxious species richness was higher with herbicide and herbicide plus tillage than other site preparation treatments, and overall herbicide plus tillage treatments tended to have numerically greatest species richness (Figure 4b).

Table 2. Mean height and diameter (±SE) change (cm) by site preparation and soil amendment treatments. Different letters within columns indicated significant differences at α = 0.05.

Treatment	**Tree**					**Shrub**		
	Populus balsamifera	***Prunus virginiana***	***Populus tremuloides***	***Picea glauca***	***Salix exigua***	***Viburnum trilobum***	***Symphoricarpos albus***	***Rosa acicularis***
Height change by site preparation treatment (cm)								
Herbicide	−6.9 (3.2)	1.3(1.0)	5.7(3.4)b	4.2(0.7)a	−9.0(3.2)b	−9.8(1.4)	0.5(1.6)ab	5.2(2.2)ab
Herbicide tillage	−2.8(1.7)	1.6(0.9)	15.8(3.5)a	5.9(0.8)a	2.0(3.1)a	−5.2(1.0)	4.4(1.9)a	6.2(2.7)a
Tillage	−7.3(2.0)	0.6(2.9)	−2.8(1.9)bc	1.7(0.5)b	−9.4(2.8)b	−8.4(1.3)	−5.4(1.2)bc	−2.0(2.1)ab
Untreated	−7.4(2.1)	−3.2(0.8)	−5.7(1.6)c	1.0(0.5)b	−9.5(2.7)b	−8.5(1.7)	−6.7(1.7)c	−3.0(1.5)b
Height change by soil amendment treatment (cm)								
Compost 100%	−3.3 (2.2)	1.9(1.2)	9.6(3.5)	5.0(0.8)a	−2.8(3.3)	−8.9(1.6)	2.4(2.1)a	6.4(2.9)
Compost 50%	−7.8(2.3)	−1.1(0.8)	0.1(3.5)	2.6(0.7)ab	−10.2(2.9)	−6.1(1.3)	−3.1(1.2)ab	−1.7(1.6)
Compost 20%	−4.9(2.3)	2.1(2.6)	0.4(1.9)	3.3(0.6)ab	−6.4(2.9)	−9.6(1.3)	−1.9(1.7)ab	1.7(2.2)
No compost	−8.3(2.6)	−1.7(0.7)	3.6(2.4)	1.8(0.5)b	−6.2(3.0)	−7.5(1.2)	−4.3(1.7)b	0.2(1.9)
Diameter change by site preparation treatment (mm)								
Herbicide	1.2(0.3)a	0.3(0.5)	1.1(0.3)ab	0.7(0.2)ab	1.3(0.3)a	0.5(0.3)	1.9(0.4)ab	1.9(0.3)a
Herbicide tillage	0.4(0.2)ab	0.4(0.2)	1.7(0.4)a	1.0(0.2)a	1.2(0.5)a	0.5(0.2)	2.8(0.5)a	1.3(0.4)ab
Tillage	−0.1(0.3)b	0.4(0.1)	0.6(0.2)b	0.6(0.1)ab	0.03(0.2)ab	0.2(0.2)	0.7(0.3)b	0.6(0.3)b
Untreated	0.3(0.4)ab	0.02(0.1)	0.1(0.2)b	0.3(0.1)b	−0.5(0.4)b	−0.1(0.2)	1.2(0.3)b	0.2(0.1)b
Diameter change by soil amendment treatment (mm)								
Compost 100%	0.9(0.4)	0.01(0.5)	1.5(0.4)a	0.9(0.2)a	0.6(0.3)	0.5(0.2)	1.6(0.4)	1.3(0.4)
Compost 50%	0.5(0.3)	0.5(0.2)	0.4(0.3)b	0.2(0.1)b	−0.2(0.5)	−0.2(0.2)	2.2(0.4)	0.9(0.3)
Compost 20%	0.02(0.3)	0.4(0.1)	0.6(0.3)ab	0.8(0.2)ab	0.4(0.2)	0.1(0.2)	1.7(0.4)	1.1(0.3)
No compost	0.4(0.4)	0.3(0.2)	1.2(0.2)ab	0.7(0.1)ab	1.1(0.4)	0.7(0.2)	0.9(0.4)	0.7(0.2)

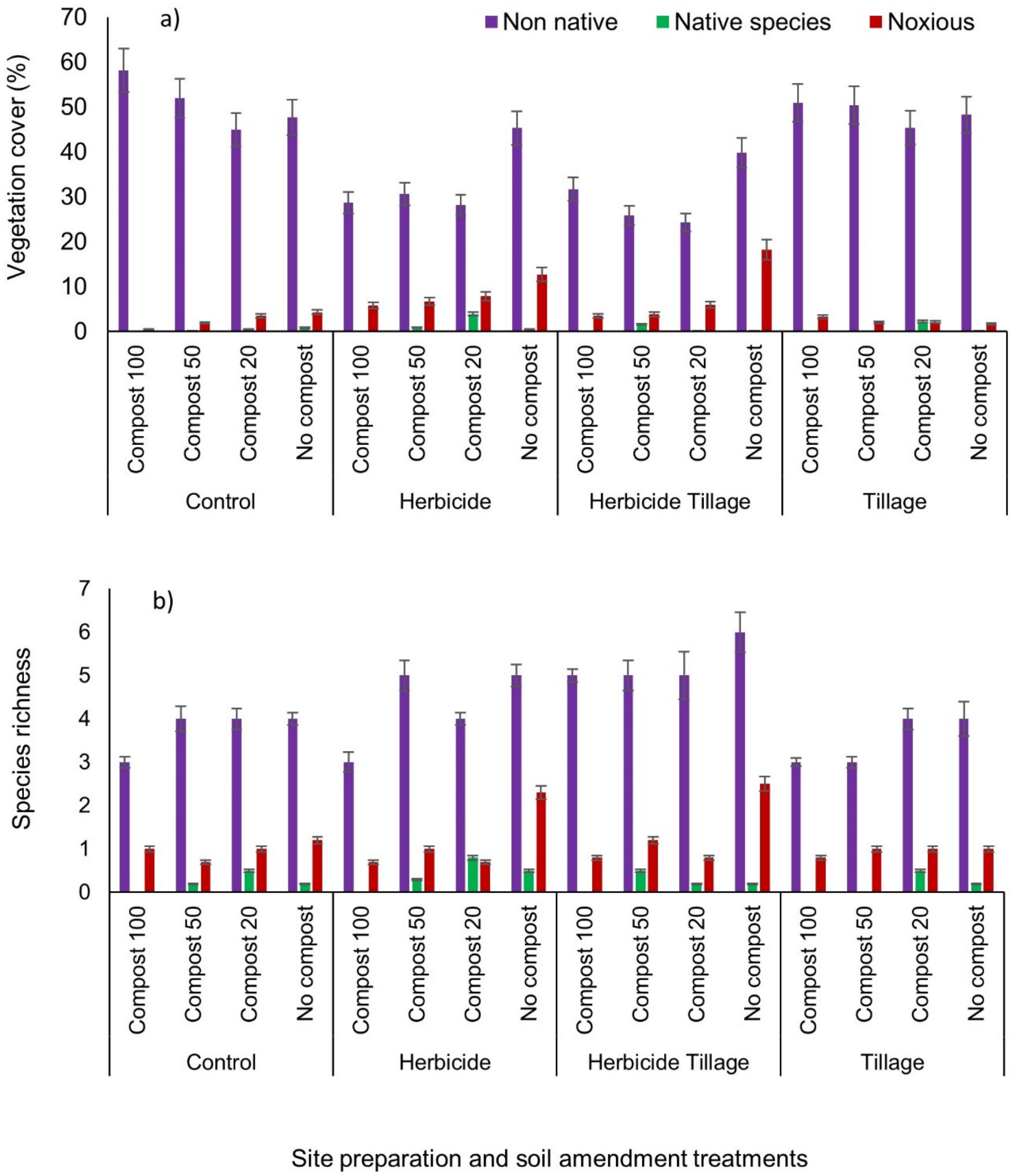

Figure 4. (**a**,**b**) Mean (±SE) percent cover and richness of native, non-native and noxious species by site preparations and soil amendments.

4. Discussion

Native woody species can survive when transplanted under appropriate conditions to naturalize areas across a city. Soil treatment (site preparation and soil amendment) prior to planting may provide advantages to newly planted seedlings by temporarily reducing competition for resources and providing nutrients to facilitate early establishment. This is consistent with the findings of Schaefer [28], where shrub species planted into natural settings flourished. Those introduced into new foundation plantings or well established but constraining environments, such as shrubs in fields or rights-of-way of dense grass, performed poorly and many did not survive. Changes in growing conditions may not benefit all species in the same way or those intended for naturalized sites, thus soil treatments should be based on the needs of the species selected for naturalization and local site conditions.

The clear difference in plant response with and without herbicide site preparation indicates that herbicide can influence naturalization of planted trees and shrubs, lowering mortality, lowering non-native species cover, and increasing native species cover. Herbicide may have suppressed non-native species and benefited planted tree and shrub seedlings through reduced interspecies competition; however, it also supported greater cover and richness of noxious weeds and native species. Outcomes of our study contradict the results of Buonopane et al. [43] who found no significant differences in vegetation cover, germinant density or species richness with and without herbicide, including noxious weeds. This suggests that to establish native species in urban environments, species competitive attributes need to be taken into consideration to decide which species to plant, and what type of site preparation treatment can be adopted to improve establishment.

Urban soils often present reductions in their most important physical properties such as structural stability and water retention. Some studies suggested that such soil properties might have detrimental effects on plant growth [44,45]. Water availability, although not measured in our study, was likely a major factor in plant response to treatment. Among the better performing species were those that are more resistant to drought, such as *Symphoricarpos albus* and *Rosa acicularis*. Plant size may have contributed to mortality as worst performing species, *Populus tremuloides* and *Viburnum trilobum*, were among the largest plants at the time of planting. These larger plants will have higher water demand for rooting and long-term establishment.

Amendments were most valuable to plant development as expressed by height and stem diameter change. In general, soil amendment did not contribute to seedling survival. Locally produced compost, especially when used at high rates can enhance growth of new seedlings due to better soil quality, including nutrient availability. A high proportion of compost clearly contributed to increased nutrients available for plants, although those nutrients were considerably mobile with concentrations declining over a year. Long term monitoring of height and stem diameter change could provide additional data on soil amendment treatment effects for species used in naturalization.

Height and stem diameter changed differently for shrub and tree species. Shrub height changes were more dynamic than those for trees, as they grew new stems from one year to the next. This makes shrubs better suited to short and mid term monitoring to measure soil treatment effects. Plant height or diameter change data were useful to assess plant development and to track predation or disturbance. A negative height or diameter change may not only be due to poor growth, but more frequently physical damage to seedlings by herbivores or human vandals pulling out the leaves, branches and plants.

The small number of native species and their sporadic occurrences at different sites and with different treatments suggest almost no native species were introduced with amendments. In contrast, two noxious weeds occurred in research plots at all locations. *Cirsium arvense* (L.) Scop. (Canada thistle) and *Linaria vulgaris* Mill. (Common toadflax) may have been brought in with materials used in the experiment and/or viable seeds were present in the seedbank and treatment application provided conditions for them to germinate, especially soil disturbance through tillage. This finding is consistent with Skrindo and Pedersen [46], who found using topsoil as an amendment to restore a roadside in Norway increased vegetation cover from one year to the next for species like *Cirsium arvense*. Noxious weed adaptations make it easy for them to naturally colonize urban spaces, making them highly effective at establishing in recently disturbed urban environments due to very high seed output, phenotypic and germination plasticity, adaptations for short and long-distance dispersal, small seed size and high seed longevity [47,48].

Treating soil of a site to be naturalized through site preparation or amendment application will most likely affect development of the plant community, including species composition and rate of development. When cover by species in our study was organized into plant categories, it became evident how desirable or undesirable the output of applied treatments can be. Naturalization must address aesthetic and ecological functions [13]; native species constitute the most desirable plant category for naturalization. Although non-native species may not need to be labeled as undesirable, management strategies should address limiting their spread while reducing and specifically eliminating noxious weeds, which truly are undesirable species and require control in some jurisdictions. Weed management is critical to urban naturalization as these areas are subject to high public visibility and usage. More rapid growth of trees and shrubs can influence attractiveness of a particular area for human disturbance or wildlife.

Compiling an integrated weed management strategy that minimizes interventions while preserving a visually appealing site appearance is a considerable challenge of naturalizing urban settings. Non-native species and other weed species have successful strategies with characteristics that facilitate successful seed banking, including high seed output, phenotypic and germination plasticity, adaptations for short and long-distance dispersal, small seed size and high seed longevity [13,48,49]. Thus, they are often difficult to control in the newly naturalized landscape where they can quickly dominate and outcompete desired species [49]. Therefore, naturalization should better facilitate favouring native species for maintaining ecological integrity. Introducing native forb species in the naturalization process could reduce spread of non-native species through direct competition. Although this 2-year study was short it provided interesting insight into site preparation and soil amendment techniques to improve success of naturalization and set it on a trajectory for longer term success.

5. Conclusions

Amendment of soil and appropriate site preparation are recommended to positively influence naturalization for urban green spaces. Site preparation with herbicide application and soil amendment with compost and topsoil influenced soil properties for naturalization, improving soil texture and increasing soil nutrients for a year. Acidity, electrical conductivity and total carbon increased, but not at detrimental levels to plants. Tree and shrub survival and growth were positively influenced by site preparation that controlled competition from existing vegetation in critical early stages of plant establishment. Herbicide was the most influential site preparation treatment, with mixed results on naturalization, as it positively increased survival and growth of planted woody species, while negatively lowering non-native species cover and increasing noxious weed cover. Soil amendments were less influential on survival than on diameter and height growth of planted trees and shrubs. Soil amendment influenced cover but not species richness. High compost amendment reduced vegetation cover across sites, and increased individual plant size. Several woody plant species responded positively to naturalization treatments. Top surviving and performing tree and shrub species were *Picea glauca* (white spruce) and *Symphoricarpos albus* (snowberry) followed by *Rosa acicularis* (wild rose). *Symphoricarpos albus* was one of the hardiest and most resilient species for planting in our naturalized area. The poorest performing tree and shrub species were *Populus tremuloides* (trembling aspen) and *Viburnum trilobum* (highbush cranberry).

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