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The Effects Of Street Tree Site Planting Width On Canopy Width And Ability To Provide Ecosystem Services

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THE EFFECTS OF STREET TREE SITE PLANTING WIDTH ON CANOPY WIDTH AND ABILITY TO PROVIDE ECOSYSTEM SERVICES

by

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Abstract

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In a time where pests such as emerald ash borer are reducing urban forests, it is important to gain a return on investment for new trees planted. Since trees cost money, the value of the ecosystem services that they provide over the course of their lives should outweigh their costs. Due to the need for a return on investment, it is important to know whether newly planted street trees are being planted in a space that does not inhibit their growth or ability to provide benefits. This study, in Lincoln, NE looks to determine the relationship between a street tree's planting space width and its ability to grow and provide ecosystem services. By measuring DBH, LCR, canopy width, height and planting space width from two species, in both parks and trees, and using i-Tree to calculate benefits, the relationship between planting space width and canopy width and benefits can all be modelled using a series of linear regressions. In the end, it was found that both canopy width and benefits were largely unaffected by planting space width, but further studies involving age could provide a better picture of the relationship relative to age.

Table of Contents

Table of Tables

Preface

Thank you to Dr. Eric North for providing me with the equipment necessary to complete the measurements necessary for this thesis. I also want to thank Dr. North for his guidance over the course of the project, providing me with valuable knowledge and insights into the process of research.

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Introduction

Street trees can be an important part of the urban environment, but do not come without costs and challenges. Understanding the relationship between the costs, benefits and challenges of growing street trees is important for understanding how to maximize the resources being put in to planting and maintaining street trees. By gaining an understanding whether a site's conditions are constraining to a street tree's ability to grow and provide benefits, it can then become possible to research whether the costs and challenges associated with a site outweigh the benefits.

Simply put, street trees are trees planted between streets and sidewalks. They are a common component of urban design, and in fact it is rare to see a street that is not lined with trees. Without them, many people would consider streetscapes to be a desolate, lifeless landscape devoid of character. Based on a study, aesthetics is contributing factor in why many homeowners decide to plant trees in the urban landscape (Conway 2015).

Not only do people appreciate trees for the aesthetic value that they provide, but there are also economic and environmental reasons why street trees are valuable. Wang et. al. (2013) found that the shade associated with trees creates a microclimate capable of regulating the internal temperature of homes, reducing energy costs and improving human living conditions. These benefits were calculated to be worth up to nearly two hundred fifty dollars per tree per year. (Wang, et. al., 2013). The same study demonstrates that trees are able to improve air quality, comparable to between 12 and 60 cents per year per square meter of tree cover, which is roughly the equivalent of purchasing and using one more high-quality air filter per year.

Nowak, et al. (2006) found the total amount of pollution removed from the air by trees and shrubs was equal to 3.8 billion dollars. Not only is this a positive financial value, but a price cannot be placed on improved quality of life for those with respiratory ailments. Trees also reduce the amount of stormwater runoff (Armson et. al. 2013), a benefit of great importance to urban areas prone to flooding. Reducing stormwater runoff can prevent excess water from reaching streams, where the accumulating stormwater from urban areas can exceed the stream's capacity.

While there are many positive benefits of trees, there can be a great deal of cost associated with both maintaining and failing to maintain trees. Activities such as pruning and irrigating may cost money in the form of labor and equipment. Failure to maintain trees can also be costly. Some of the most common causes of death in urban trees include pests and storm damage (Koesser et. al. 2016). The risk for these two causes of death can be limited through frequent maintenance. There are some pests that can be treated using pesticides, and frequent pruning can reduce the risk of storm damage. If trees are not maintained, it is possible that their risk of dying may increase, and in that case, they will need to be removed, which is an additional cost. Beyond costs directly to maintain the tree, there can also be unintended consequences. For instance, if a tree fails in an urban environment, it unfortunately has a wide range of potential targets, including powerlines, homes, and vehicles. Trees also have the potential to cause harm to human health, both directly from allergies or branches failing and landing on people, as well as psychologically in the instance where a tree may create a darker environment at night leading to fear of crime. (Roy, et. al., 2011)

The benefits lost from trees are exacerbated by planting trees in locations that are not suitable for their proper growth and development. One potential instance where this may occur is planting street trees in far too small of growing spaces. Street trees are often planted in the narrow strip between the street and a sidewalk. As the tree in the small space grows and its roots expand, they can cause damage to infrastructure such as sidewalks. The same problem can be caused by the trunk expanding beyond the available space allotted, causing the sidewalk to crumble or be moved out of its place (Randrup et. al. 2013). One city in Randrup's (2013) study was found to pay up to $10.67 per capita in one year on repairing sidewalks and curbs after damage was caused by trees, as well as $5.85 per capita in one year in an attempt to mitigate the risk for future damage. According to the same study, the primary factors for the conflict are planting trees too large for their site, limited soil volume, shallow topsoil, and inadequate distances between the trunk and the sidewalks.

Another cause for cost in street tree plantings is their relatively short life span, particularly when compared with trees planted in other locations. In Philadelphia, the average life span for street trees was between 19 and 28 years. While this is relatively short, based on the study, it appears to be on the longer end of the spectrum for street trees. It was found that in previous studies in other cities, the average life span ranged from only seven to 13 years for street trees. (Roman & Scatena, 2011). Potential areas of concern based on the study by Roman & Scatena, (2011) are the cost effectiveness of street trees and factors reducing their lifespan potential. For an average lifespan of seven to 13 years, tree removal expenses coupled with replacement tree planting and maintenance costs can be significant. Further consideration of the reduced lifespan of street trees brings forth the question of what factors are decreasing the lifespan of street trees?

When looking more specifically at the causes of mortality in street trees, there are a few factors that frequently result in increased mortality. The factors shown to consistently increase mortality in street trees are increased diameter, decreased planting space width, decreased condition and adjacency to construction (Koeser et. al., 2013). Decreases in planting space width being a factor that increases tree mortality is particularly relevant to the study at hand. The increased mortality of street trees as planting space width decreases suggests that there may be a minimum threshold of planting space width that is viable for street tree growth. The study by Koeser et. al., (2013), provides a need for further questioning. What is the cause of increased mortality in street trees in smaller planting space widths, and do these effects impact more than just tree mortality?

One factor that may be greatly reducing the lifespan of the street trees in smaller planting spaces as seen in the study by Koeser et. al., (2013), is limited rooting space. The location of street trees may be problematic, as the construction of roads entails significant compaction of the soil immediately beneath the street. Significant soil compaction coupled with the impermeability of the concrete surface of the road create an area that is unfavorable for the growth of roots. The two factors needed for root growth are oxygen and water. With the compaction of the soil beneath the road eliminating pore space, oxygen becomes unavailable, and with water unable to penetrate the concrete surface of the street, water is also unavailable. The combination of these factors limits root growth beneath roads. (Schroder, 2008). If root growth is limited underneath roads, that begs the question for street trees of where do the roots grow? The result of limited root growth beneath roads is a very narrow strip of ground in which the roots can grow effectively. While the root zone conditions associated with a sidewalk are not necessarily as extreme as a road, they can still be greatly limiting. A street tree with a larger planting space between it and the sidewalk may find itself growing roots more favorably, as it has adequate space for root development than a tree with a smaller space.

Not only does it appear as though planting a large street tree in too small of a space can create major infrastructure conflicts and damage, but it also appears as though it can affect the trees planted in those spaces. Roots may be limited to an area only a few feet wide in which they can grow. Limited space for rooting growth can be detrimental to the growth and development of trees. In a study done to demonstrate the effects of different nursery production systems, it was shown that trees grown in open fields put on a greater density of root growth than trees grown in containers. (Gillman 1996). While the scenario from the study is different from street trees, it bears some similarities, as the rooting space being confined to a limited area is not unlike the restrictions created by a container. In that study conducted by Gillman (1996), not only was root density found to be decreased when growing in containers, but also that both the stem growth and shoot growth were limited as well. Another study, specifically featuring peach trees found a similar result to the Gillman study. The peach trees were grown in five different soil volumes, and the trees with the greatest soil volumes put on the greatest amount of growth, ranging greatly in size from the smallest rooting volumes to the largest rooting volumes. (Boland, et. al., 2000).

The limited canopy and stem growth noted in nursery trees with smaller root volumes potentially causes issues when scaling this scenario up to street trees. For trees to maximize the benefits that they are providing, they need to have large, dense canopies. In the case of providing microclimate benefits, a tree with a small canopy provides very little benefit. (Sanusi, et. al., 2017). Therefore, if a tree can provide benefits, based on the previously mentioned studies about soil volume, trees likely need to have adequate soil volume for rooting in order to provide the maximum benefits. The lack of possible rooting space for street trees, as limited by the concrete, may then limit the ability of street trees to provide benefits.

Street trees may be facing growth limitations beyond just confined root space. The above ground environment for street trees may also be potentially limiting. Concrete absorbs heat and re-radiates it throughout the day. The radiation of heat by concrete has been shown to create higher temperatures in areas with higher concentrations of concrete infrastructure than areas that have more vegetation (Takebayashi, & Moriyama, 2009). Trees that are planted in sites where concrete is more abundant may face challenges in overcoming the higher temperatures. The higher temperatures are shown to increase the evaporative demand, causing less favorable water conditions for trees planted in areas with high concentrations of concrete. The trees grown in these sites have also been shown to have decreased crown and diameter when compared to trees grown in other sites (Kjelgren & Clark, 1992). The reduction in crown in sites with more concretes could potentially be a problem in different street tree sites as well. When a street tree is planted in a wide space, much of the tree will be growing over grass. On the other hand, a street tree in a small space will have much more of its canopy extending over concrete. The increased exposure to concrete in street trees with smaller space widths may be a potential factor in the canopy width of street trees, depending on planting space width.

Ultimately, the potentially limiting growing conditions associated with street trees, combined with their associated costs lead to a key area of importance. If cities are regularly planting trees, they are spending money to purchase the tree, maintain the tree, repair infrastructure damage and remove the tree at the end of its life. If the tree's size is limited and its ability to provide ecosystem services is limited, then the return on the investment is diminished. Attaining a significant return on investment for street trees is a particularly pertinent issue to Lincoln, as the city will soon begin losing significant portions of their trees to emerald ash borer. The city will attempt to replace many of the lost trees, which will require sizeable expenditures.

If the city were to understand which sites are limiting to a tree's ability to provide benefits, they could focus their planting efforts on sites that are better suited.

Objectives

The objectives of this study are important for understanding the suitability of street tree planting sites. The objectives are: 1) determine the effect of planting space width on street tree canopy width; 2) provide insight as to whether the width of a planting site is a determinant to a street tree's ability to provide ecosystem services to humans, and 3) determine which planting widths are best suited to allow a street tree to grow to a size capable of providing benefits. Answering these three questions will allow cities with a tool necessary for understanding whether a planting space too small to provide a return on their investment.

Methods

The study took place in the city of Lincoln, NE. Within the study, there were two specific site types. The first are boulevard plantings, or the space between the street and the sidewalk. The boulevard plantings are included in the study to understand their potential impact to tree growth. There will be 40 total trees measured from the boulevard site type, randomly selected from Lincoln's tree inventory database. The random selection from around the city will provide a wide range of different planting widths. Trees measured from the boulevard site type will be compared to park plantings, which will serve as the control, as there should be no inhibition of root growth, allowing the trees to grow unrestricted. The width of the planting spaces will be measured using a tape measurer.

The trees that will be tested in this study are common hackberry (C*eltis occidentalis),* and northern red oak (*Quercus rubra).* Under the city's approved street trees list, each of these trees is listed as large trees (City of Lincoln). Large trees are more likely to be impacted by the constraints of boulevard planting spaces due to their more extensive root systems. Due to the increased risk of large trees having roots impacted by planting space, they were chosen for this study. Additionally, these two tree species have been chosen due to their common occurrence as street trees in Lincoln.

From each species, 40 individuals were measured, with 20 of each tree species measured in each of the two site types, with 80 total trees measures. The use of 40 trees from each site was decided upon, as that will provide enough samples to have diversity in both the size of trees, as well as the size of the planting space width. Many different measurements will be taken for each tree. The first measurement is DBH (diameter at breast height, 4.5 feet), which was measured using a Forestry Suppliers Inc. 5m DBH tape. DBH is measured in centimeters. The second measurement taken was tree canopy width, which was measured in two directions: North/South, and East/West. The two canopy width measurements were then be averaged to provide a more representative measure of canopy width for use in the study. Canopy width was measured using a Keson 50 feet measuring tape, and the data collected for canopy width was measured in meters. The third measurement taken was tree height which was measured by using a Suunto clinometer and the Keson measuring tape. The data collected for height was measured in meters. The fourth measurement taken was live crown ratio (LCR). LCR is a percentage of the total tree that the canopy comprises. LCR is derived from measuring the total height of the tree, as well as the height of the bottom of the crown. LCR was measured using the Suunto clinometer, as well as the Keson measuring tape. LCR is measured as a percentage. The final physical measurement taken was planting space width. Planting space width, which measures the width between a sidewalk and a street in which a street tree was planted. Planting space width was measured using the Keson measuring tape and was measured in meters.

Once the physical data was collected for each tree, the i-Tree Eco software (i-Tree Software Suite v6) was utilized to determine the annual value of ecosystem services provided by each of the trees in the study. The i-Tree software uses tree species as well as DBH, LCR, tree height, and canopy width to calculate a monetary value provided by the tree's ecosystem services. The monetary values provided by i-Tree will quantify the ecosystem benefits provided by each tree, allowing the trees from each of the sites to be compared to determine if planting width impacts a tree's ability to provide ecosystem services.

In order to analyze the data collected, a series of four multiple regressions models will be used. The regression models, as numbered below, will measure the following:

1) The relationship between canopy width and planting space accounting for DBH, species, and site (park/street).
2) The relationship between canopy width and planting space accounting for DBH and species. To better determine the effects of these variables on street trees, only street trees will be used in this model.
3) The relationship between canopy width and ecosystem services provided accounting for DBH, LCR, species, site, height and canopy width.
4) The relationship between canopy width and ecosystem services provided accounting for DBH, LCR, species, height and canopy width. To better determine the effects of these variables on street trees, only street trees will be used in this model.

In order to include park trees in these tests, a value of their planting site width was generated by calculating the approximate area underneath each tree's crown.

Results

Table 1. Descriptive Statistics of Variables

	Park Oak	Street Oak	Park Hackberry	Street Hackberry
Average DBH(cm)	50.39(19.30)	56.40(17.50)	50.13(17.94)	54.51(20.67)
DBH Max(cm)	84.50	82.00	84.00	82.00
DBH Min(cm)	18.00	26.25	18.00	20.00
Average Height(m)	13.62(4.48)	15.55(6.45)	16.85(4.91)	14.87(4.08)
Height Max(m)	22.50	22.50	22.20	22.05
Height Min(m)	4.50	5.75	8.00	8.50
Average LCR(%)	74.40(11.90)	69.30(10.79)	71.08(9.43)	69.38(12.92)
LCR Max(%)	90.40	87.12	81.82	87.93
LCR Min(%)	32.50	43.48	50.00	43.86
Average Canopy Width(m)	11.80(3.48)	12.65(3.00)	11.02(3.62)	11.76(3.49)
Canopy Width Max(m)	16.95	17.38	17.60	16.80
Canopy Width Min(m)	5.05	7.65	4.50	5.48
Average Planting Space(m)	119.49(64.10)	4.62(2.04)	211.17(126.14)	4.36(1.86)
Planting Space Max(m)	225.64	9.30	486.57	7.25
Planting Space Min(m)	20.03	2.50	31.81	1.60
Average Benefits($/yr)	7.95(4.00)	9.00(3.72)	8.96(4.62)	9.97(5.03)
Benefits Max($/yr)	15.50	16.36	18.42	17.84
Benefits Min($/yr)	1.37	2.65	1.66	2.33

Note: Standard Deviation in Parenthesis

Quality Control: Random selection of street trees, combined with the large sample size provided a wide range of tree sizes, as well as a wide range of planting space widths from across the city of Lincoln.

Table 2. Regression Outputs for All Four Models.

	Canopy Width(all)	Canopy Width (street only)	Benefits (all)	Benefits (street only)
Intercept	2.037(0.503)***	0.3.043(0.841)***	-7.315(0.850)***	-7.161(1.039)***
Space	0.010(0.002)***	0.037(0.112)	0.001(0.002)	-0.183(0.077)*
Oak	1.159(0.318)***	0.580(0.438)	-1.560(0.258)***	-1.822(0.290)***
Street	1.664(0.512)**		0.370(0.409)	
DBH	0.142(0.010)***	0.157(0.012)***	0.099(0.016)***	0.079(0.022)**
LCR			3.833(0.999)***	3.980(1.252)**
Canopy Width			0.656(0.086)***	0.743(0.111)***
Height			0.070(0.036)	0.144(0.058)*
R^2	0.856	0.841	0.957	0.967

Note: Statistical significance: *** p > 0.001, ** p > 0.01, * p > 0.05

The multiple regression model run for predicting canopy width based on planting space size accounting for DBH, species, and site, found all of the variables to be significant, as each had p-values of less than 0.01. Additionally, as can be seen in table 2, when planting space width increased by 1m, mean canopy width increased by 0.010m. Oak increased the mean canopy width by 1.159m when compared to hackberry. Street trees had a 1.664m increase in mean canopy width when compared to park trees. When DBH was increased by 1m, mean canopy width increased by 0.142m. The R^2 value of 0.856 from this regression model indicates that 85.6% of the variation in the model can be explained by the variables, and 15.4% of the variation is explained by other factors.

When looking at only street trees in the second model, DBH ($p < 0.001$). is the only significant variable. When looking at table 2, when planting space increased by 1m, canopy width increased by 0.037m. Oaks increased the mean canopy width by 0.580m compared to hackberry. When DBH increased by 1cm, canopy width increased by 0.157m. The R^2 value of 0.841 from this regression model indicates that 84.1% of the variation in the model can be explained by the variables, and 15.9% of the variation is explained by other factors.

The third regression model, model canopy width($p<0.001$), LCR($p<0.001$), DBH($p<0.001$), and species($p<0.001$), were all found to be statistically significant. As can be seen in table 2, when planting space width increased by 1m, mean benefits increased by $0.001. Oak provided a mean increase of -$1.560 in benefits when compared to hackberry. Street trees provided a mean increase of $0.370 in benefits compared to park trees. When DBH increased by 1cm, mean benefits increased by $0.099. When LCR increased by 10%, mean benefits increased by $3.833. When canopy width increased by 1m, mean benefits increased by $0.656. When height increased by 1m, mean benefits increased by $0.070. The R^2 value of 0.957 for the third model indicates that 95.7% of the variation in the model can be explained by the variables and 4.3% is explained by other factors.

In the fourth regression model space($p=0.024$), species($p<0.001$), height($p=0.018$), LCR($p=0.003$), canopy width($p<0.001$) and DBH($p=0.001$) were all statistically significant. As can be seen in table 2, when planting space width was increased by 1m, mean benefits increased by -$0.183. Oaks had a mean increase of -$1.822 in benefits when compared to hackberry. When DBH was increased by 1cm, mean benefits increased by $0.079. When LCR was increased by 10%, mean benefits increased by $3.980. When canopy width increased by 1m, mean benefits increased by $0.743. When height was increased by 1m, mean benefits increased by $0.144. The R^2 value of 0.967 for the fourth regression indicates that 96.7% of the variation in the model can be explained by the variables tested, while 3.3% of the variation results from other factors.

Discussion

This study was able to provide evidence to answer the three objectives outlined for the study. The three objectives are: 1) determine the effect of planting space width on street tree canopy width; 2) provide insight as to whether the width of a planting site is a determinant to a street tree's ability to provide ecosystem services to humans, and 3) determine which planting widths are best suited to allow a street tree to grow to a size capable of providing benefits.

Regarding objective 1, planting space width had minimal effect on street tree canopy width, and DBH was found to be the only measured variable found to be an accurate predictor of canopy width. DBH was the only variable to have been significant in both the first and the second. Beyond that, DBH was the only variable significant in the second regression, which used only street tree. Beyond the statistical significance of DBH, changes in DBH strongly related to changes in canopy width. In the first model, when DBH increased by 1cm, canopy width increased by 0.142m. The relatively small increase shown may be misleading, as the unit of measurement are different. When adjusting them to both be in centimeters, when DBH increased by 1cm, canopy width increased by 1.42cm. The result is similar in the second model, with 1cm of DBH increase, canopy width increased by 0.157m or 1.57cm. Such high numbers indicate that any change to DBH will result in large changes to canopy width, so DBH has a substantial effect on canopy width.

On the other hand, the planting space width had little effect on canopy width both with and without park trees included. When looking at the first regression the results may be a bit misleading, as they show planting space width to be statistically significant. However, this does not give the most accurate picture of planting space width's ability to predict canopy space.

When looking further into the results of the first regression, it was found that a 1m increase in planting space width only increased mean canopy width by 0.01m. When pairing the relationship with the statistical significance, it becomes clear that the changes in planting space width had little effect on the canopy width.

The measure for planting width in street trees was created as a function of canopy width, so there is a good chance that much of planting space's ability to predict canopy width from the first regression results from that. When looking at the second regression with only street trees, it becomes even more apparent that canopy width is largely unaffected by changes in planting space width. When planting space width increased by 1m in this model, mean canopy width only increased by 0.037m. Increases of planting space width in this model again resulted in nearly zero change in canopy width. While this study indicated a weak relationship between planting space width and canopy width, this is not to say that planting space width could not potentially be impactful in street trees, but rather that this study did not consider enough variables. Further study including the age of each tree could provide a more comprehensive picture of the impacts of canopy width on tree growth relative to age.

Similar to canopy width, annual value of ecosystem services was shown to have been largely unaffected by planting space width. Planting space as a variable was not shown to be statistically significant in the third regression. The lack of statistical significance demonstrates that planting space is likely not a factor on a tree's ability to provide benefits. In addition to a lack of statistical significance, increases in planting space width of 1m only increased mean benefits by $0.001. There is nearly zero effect of planting space width on benefits.

When looking just a street trees in model 4, the results differ. Planting space was a statistically significant variable in the regression model with only street trees. Beyond statistical significance, change in planting space width had a much large effect on mean benefits. By increasing planting space width by 1m, mean benefits were found to increase by -$0.183. While not a large change by any means, it is not something that can be ignored. When considering the potential for a planting space to be beyond 7m wide, losing an average of 18 cents per meter of planting space can add up to over $1 lost annually. When looking at the effects of other variables on benefits, the effects of planting space appear to be diminished. DBH, canopy width, LCR, and species all had substantial effects on benefits provided. When DBH increased by 1cm, mean benefits increased by $0.079, a number that quickly adds up to substantial benefits when considering the mean DBH of trees measured was over 50cm. LCR when increasing by 10% resulted in a mean increase in benefits by $3.98, which is again a substantial increase. Canopy width when increased by 1m resulted in a mean increase in benefits of $0.743, which is another substantial relationship. Planting space width may have some effect on benefits but the effects of DBH, canopy width and LCR far outweigh any effects of planting space width. Much like with canopy width, further study is needed involving age to better understand the effects of planting space width on ecosystem services provided relative to age.

The answers to the first two objectives provide the answer to objective 3. By determining that planting space width has minimal effect both canopy width and benefits, it becomes clear that there were no sites that better allowed street trees to grown and provide benefits. This is again, not to say that there may not be planting space widths that are less suitable to a street tree's growth, just that the study did not find planting space width to have a substantial effect. Further study that considers the age of trees, and potentially even a long term study of newly planted trees would provide much more insight to the relationship between planting space width and a street tree's ability to grow and provide benefits relative to its age.

The results of this study differed substantially from the results of other studies done involving the relationship between limited root space and canopy growth. For instance, the study by Gilman, (1996) found trees grown in containers to have limited canopy growth compared to trees grown with larger soil volumes. The lack of effect on canopy growth found in this study, likely reflects that the roots may have extended well beyond the measured planting space width. There are a few possibilities involving the roots. The first of which is that sidewalks may be substantially less limiting to root development than streets. Based on the study by Schröder, (2008) that demonstrated the restrictions on root development that streets create, it was assumed that sidewalks would have similar effects on root growth. It is possible that sidewalks do not create the same root limiting conditions as streets or do to a lesser degree that still allows root growth underneath. Alternatively, trees may have been planted and developed substantial root systems long before sidewalks were constructed. In either case, not knowing whether roots were constrained to the measured planting space width or not could be a substantial factor in not seeing any effects on canopy growth.

Similarly, the differences in the above ground environment between different street tree planting space widths may have been minimal. The study by Kjelgren & Clark, (1992) that found canopy to be reduced in sites with greater concentrations of concrete was measuring the difference between street trees and park trees. The increased grass cover in street tree sites with wider planting space widths likely did not have a large enough difference in grass coverage to change any effect that the increased temperatures from concrete may have had.

Summary and Conclusion

Planting space width was found to have minimal effect on the canopy width of street trees. One meter of increase in planting space width resulted in almost zero change in canopy width. On the other hand, changes in DBH resulted in substantial changes in canopy width. Value of ecosystem services, much like canopy width, are largely unaffected by planting space width. Increasing planting space width actually resulted in a small decrease in benefits (-$0.18/m), but compared to the large effects that DBH, canopy width, LCR and species had on benefits, the small effects of planting space width are largely insignificant. Finally, the study showed that due to planting space width having minimal effect on canopy width or benefits, that there are no planting sites found be any more limiting to street tree growth than others. If there had been more time to conduct this study, it would have been beneficial to also determine the age of the trees being studied. Knowing the age would have provided more insight as to whether canopy width and benefits were affected by planting space width relative to their age.

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