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THE COST OF SHADE: COST-EFFECTIVENESS OF TREES VERSUS BUS SHELTERS

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Abstract. Shade at bus stops can enhance the thermal comfort of waiting riders and can encourage new passengers, thereby reducing air pollution and traffic congestion. This study used computer simulation to compare the cost-effectiveness of shade provided by metal shelters versus trees at 64 bus stops in Tucson, Arizona. The 40-year projected total future and present values of costs were over 50% greater for shelters than for trees. When differences in the amount of shade provided over time were considered, a 20% cost savings was projected for trees. Expenses for irrigation and pruning accounted for about 95% of all projected tree costs. These findings suggest that trees can be a cost-effective substitute for shelters at bus stops in mid-latitude cities where shade is useful.

Trees at bus stops provide protection from sun, wind, and rain for waiting passengers, as well as other environmental and aesthetic benefits (e.g., dust interception, absorption of gaseous pollutants, conserving carbon dioxide, wildlife habitat). Despite these benefits, tree plantings are seldom purposefully designed for bus stops. Instead, metal bus shelters traditionally are used for passenger protection. This study evaluates the cost-effectiveness of trees versus metal shelters along a bus route in Tucson, Arizona to determine if trees could be a less expensive substitute for bus shelters.

Like many other U.S. cities, Tucson, Arizona experienced rapid population growth during the past 40 years. One environmental impact of urbanization is air pollution, in Tucson primarily due to vehicular emissions. Concentrations of carbon monoxide and particulates exceed E.P.A. air quality standards at certain times in Tucson. In an effort to meet standards, local governments and businesses support educational and incentive programs that encourage citizens to ride the local bus system.

Accessibility, comfort, and adherence to schedules are key factors influencing bus ridership. Because of Tucson's hot arid climate, shade at bus stops contributes to user comfort. Passenger requests chiefly focus on the dual needs for shade and seating; however, seating without shade is considered to be inadequate (pers. comm., George Patton, Sun Tran, Feb. 25, 1990). Shade at bus stops improves the comfort of current riders and encourages new riders. Greater use of mass transit is likely to enhance the quality of life for the entire community by reducing air pollution and traffic congestion.

Transit Management of Tucson (Sun Tran) is contracted by the city to operate the bus system. Sun Tran has 2,100 bus stops, 412 with shelters that provide shade via roof panels. Of those shelters, 272 are of the newer type that can provide additional shade from screening panels added to the back, front, and sides. Sun Tran's goal is to add 50 new shelters per year. The costs of new shelters are shared, with 80% of the funding provided by the Urban Mass Transit Administration (UMTA), a U.S. Department of Transportation Agency, and 20% contributed by local sources.

Trees are a "living technology" that can enhance thermal comfort at bus stops if used alone or in conjunction with metal shelters. Although there is no municipal urban forestry program in Tucson, Trees for Tucson/Global ReLeaf (TFT/GR) is a citizen-based program whose goal is to plant 500,000 desert-adapted trees in Tucson and eastern Pima County by 1996. TFT/GR is sponsored by Tucson Clean and Beautiful and endorsed by numerous civic organizations. Local interest in tree planting at bus stops is evidenced by the 1990 Arbor Day tree planting ceremony at a bus stop and by results of a resident survey indicating that 50% of the respondents identified bus stops as being "very important" sites for tree plantings, second only to parks (1).

Although trees might substitute for metal bus shelters, the decision to develop and implement a planting program first requires a long-term comparison of costs for trees and shelters. Trees require years to produce shade equivalent to that provided initially by bus shelters. Costs for site preparation, planting, maintenance, and replacement of trees can be substantial. In this water-scarce region, initial irrigation is critical to survival and can be costly as well. Additionally, costs for tree shade can vary depending on whether all operations are contracted out, or TFT/GR and its volunteers provide certain materials and services at no cost to Sun Tran. Therefore, this study uses a life-cycle costing approach to compare the 40-year costs for shade provided by trees and metal shelters along one bus route in Tucson (8).

Methods

Bus Stop Survey. A survey of bus stops without shelters along Sun Tran's Route #8 was conducted to identify their relative suitability for tree planting. Route #8 is Sun Tran's busiest route and passes through a variety of land uses including the downtown business and arts district, strip commercial development, and multiple and single family residential areas. The route has a one-way length of 19 miles (30 km).

Each unsheltered bus stop was field checked to determine if there was 1) adequate aboveground space for a tree, 2) pavement requiring removal before planting, and 3) irrigation in-place. It was assumed that a single tree would be planted 5 ft (1.5 m) behind or next to the bench on the non-approach side. The latter constraint insures that trees do not obstruct the visibility of approaching buses. Factors contributing to inadequate planting space included the presence of healthy trees, commercial buildings/awnings or obstructions within 6 ft (2 m), planting strips less than 3 ft (1 m) wide, and steep slopes.

The suitability of each site for tree planting was categorized as: *Excellent* for bus stops with adequate planting space, no pavement, and in-place irrigation; *Good* for stops with all the above features except in-place irrigation; *Fair* for sites with adequate space, lacking in-place irrigation, and requiring removal of pavement prior to planting; and *Unsuitable* for for stops already treed or lacking adequate space for other reasons.

Modeling Approach. A microcomputer spreadsheet program was used to project average annual costs for a 40-year planning period (1990-2030). All metal shelters and trees were assumed to be installed in 1990. Costs for acquisition of additional right of way, benches, and trash pick-up

Table 1. Modeling assumptions for the TFT/GR and contract scenarios ($/tree)

Scenarios locations	*Concrete removal*	*Trees/ plant*	*Irrig. hook-up*	*Irrig.*	*Prune*	*Remove*	*Replace*
TFT/GR							
Excellent	—	TFT	TFT	TFT	*	*	TFT
Good	—	TFT	—	225	*	*	TFT
Fair	150	TFT	—	225	*	*	TFT
Contract							
Excellent	—	65	100	TFT	*	*	65
Good	—	65	—	225	*	*	65
Fair	150	65	—	225	*	*	65

TFT = expenses borne by TFT/GR and partners
* = expenses vary with tree size

were not included in this comparative analysis because expenses would be similar for shelters and trees.

Three scenarios were modeled (Table 1). The first scenario, called *Shelter*, projected costs for a metal shelter at each bus stop. The second scenario, called *TFT/GR*, assumed all trees were obtained and planted by TFT/GR volunteers at no cost to Sun Tran. It also assumed that costs for irrigation hook-up and water for trees planted at locations categorized as Excellent were contributed by adjacent businesses as part of a proposed Adopt-A-Bus Stop program. Maintenance costs that were contracted out included pruning, dead tree removal, irrigation for trees at locations designated as Good and Fair, and pavement removal for planting at sites designated as Fair. The third scenario, labeled *Contract*, assumed all costs associated with tree planting and maintenance were contracted out by Sun Tran, except irrigation water at Excellent sites.

Shelter Costs. Each new shelter costs about $3,000, including design, project management, fabrication, excavation, pouring the concrete slab, and construction. Annual repair costs were estimated to be $113. Metal shelters have an average life expectancy of 20 years. Removal costs and replacement costs are approximately $250 and $2,250, respectively. Replacement costs are less than original installation costs because the original concrete slab is retained. In this 40-year cost analysis it was assumed that each shelter was installed in 1990, removed and replaced with a new shelter in 2010, and then removed in 2030.

Tree Costs. The tree cost simulation model used here is an adaptation of a model previously used to project benefits and costs for a large scale tree planting (4). Three major components of the model are: tree population, tree size, and cost analysis. The tree population component incorporates expected mortality and calculates tree numbers. Dead trees were assumed to be replaced by new plantings during the same year. Hence, the tree population was modeled to move from an even-aged stand in 1990 to an increasingly uneven-aged stand as trees died and were replaced. The tree size component calculates total leaf area using data on projected growth rates. The third component projects costs on a per unit leaf area and per stem basis. The following sections describe methods and assumptions used in the three components of the tree cost model.

Tree type, leaf area, and pruning and removal costs. A prototypical model of a native velvet mesquite *(Prosopis velutina)*, a popular tree because of its rapid growth, drought tolerance, and moderately dense shade, was used to model all trees. Mature crown size was assumed to be 25 ft tall and wide. A leaf area index (LAI) of 3 was assumed based on preliminary research data from an open-grown mesquite tree in a Tucson park. Leaf area (LA) was calculated using a ground projection (GP) term, where GP is the area under the tree crown dripline:

$$LA = LAI \times GP \quad (1)$$

Pruning and removal costs were directly linked to leaf area because they generally increase as leaf surface area increases. Based on data from local arborists, the cost for pruning ($250) and removing ($400) a mature mesquite tree was divided by the total leaf area (1,473 sq ft) to derive values per sq ft of leaf area for smaller trees. These costs were calculated to be $0.17 and $0.27 per sq ft of leaf area for pruning and removal, respectively.

This approach assumed that costs were linearly related to leaf area, and this is not always true. For example, pruning and removal costs may

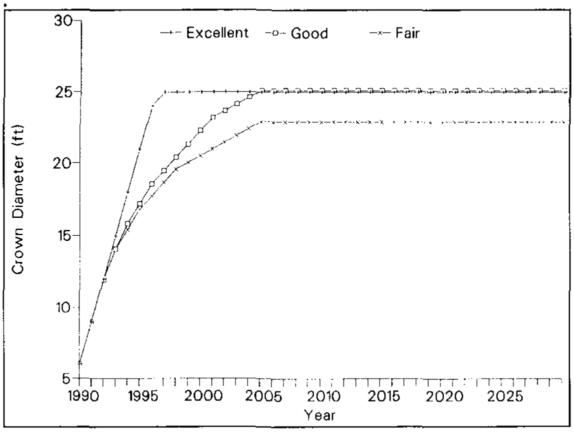

Figure 1. Projected tree sizes illustrate effects of different location-related irrigation rates and site conditions on growth rates.

increase non-linearly when more expensive equipment is required to work on larger trees. All trees were assumed to be pruned on a five year cycle. Costs for removal accrued based on projected mortality over the 40-year period (Table 2).

Growth rates and irrigation water costs. Growth rates were calculated for trees in each site and were directly related to estimated irrigation rates and site conditions. A potential evapotranspiration rate (PET) for mesquite in the Tucson area was assumed to be 19.8 in/yr (7). Although desert trees such as mesquite benefit from ample irrigation during their first years, they can perform reasonably well with little supplemental irrigation after establishment. However, growth rates will slow as drought stress increases.

Growth rates were linked to irrigation rates by first determining the amount of irrigation water required to achieve the average maximum annual growth increment (MAGI), assumed to be 3 ft (1 m), using the following equation (10):

$$PET_t = PET \times (0.4896 \times CD^2) \qquad (2)$$

where

PET_t = potential evapotranspiration per tree (gal/yr)
PET = evapotanspiration (ET) rate for mesquite (in/yr)
CD^2 = crown diameter squared (sq ft)

and 0.4896 is a constant in the consumptive water use equation.

Annual growth increments (AGI) were related to irrigation rates using a growth curve modeled as a sine function (3):

$$AGI = MAGI \times PMGI \qquad (3)$$
$$PMGI = SIN\ (PPET \times 1.57) \qquad (4)$$
$$PPET = AET / PET_t \qquad (5)$$

where

PMGI = fraction of average annual maximum growth increment (0 to 1)
PPET = ratio of actual to potential ET
AET = actual ET based on irrigation rate (gal/yr) and other terms are described above.

Hence, PPET and resulting growth rates varied across locations due to different irrigation rates (Figure 1). Also, relatively slower growth rates were anticipated for trees in locations designated as Fair because trees were in small (30 sq ft) planting holes surrounded by paving and buildings. We arbitrarily reduced PPET by 5% to retard the growth of these trees.

Irrigation rates and water costs were based on a series of assumptions for each location and planting scenario (Table 1). In both the TFT/GR and Contract planting scenarios, trees at Excellent sites were provided free irrigation by adjacent businesses with a maximum delivery of 4,000 gal/yr. Connecting new trees to the in-place irrigation was assumed to be done at no cost to Sun Tran in the TFT/GR scenario, and at a cost of $100 per planting hole for the Contract scenario. It was assumed that trees at sites designated as Good and Fair were irrigated from a water truck for 15 years following planting, whereupon they required no additional irrigation. Each 6'x 6'x 6" tree basin was filled (22 gal) weekly during the 8 months (March through October) when irrigation is desirable for desert trees in Tucson. A survey of local contractors indicated that irrigation by water truck would be the least expensive means of water delivery. Irrigation by water truck was assumed to cost $40/hr, including labor and water. Watering all trees in Good and Fair sites by truck along Route #8 was estimated to take approximately 7 hours per trip.

Mortality rates. Vandalism, damage from vehicles, improper planting and maintenance, and storm damage are examples of factors likely to influence life span and loss rates for trees in Tucson. Personal observation suggests that the life span of the mesquite is reduced from over 100 years in the desert to 50-75 years in the city.

Three types of mortality were projected for trees at each site: Type A) establishment-related losses for young trees; Type B) age-independent losses due to weather, site modifications, insect or disease attacks, etc. (considered constant over time); and Type C) senescence-related losses associated with aging (Table 2) (6). Initial annual mortality rates (Type A and B) were assumed to be 2.75%, 5%, and 7.25% for trees at Excellent, Good, and Fair sites, respectively. These loss rates were greater than the 1-2% annual rates used by Richards in his study for Syracuse, New York (6), but less than the 17% average annual loss rate recorded by Nowak and others in their study of a boulevard planting in Oakland, California (5). Mortality rates for Type B and Type C losses also increased as site suitability decreased, and were more conservative than values used in the Syracuse study (6).

Planting and replacement costs. The cost for initial and replacement planting at Excellent and Good locations in the Contract scenario was assumed to be $65 per 15 gal mesquite tree (Table 1). This price includes costs of the tree, site preparation, planting, staking, and clean-up. Planting cost at Fair locations was assumed to be $215 per tree, with $150 spent initially to remove 30 sq ft of pavement. In the TFT/GR scenario, pavement removal was the only planting expense because the trees and their planting were assumed to be no-cost contributions. Replacement costs were assumed to equal initial planting costs except at Fair sites, where costs for pavement removal were considered for the initial planting only.

Cost-Effectiveness Analysis. Annual costs were calculated and compared for each scenario. Prices of materials and labor were assumed to remain constant over the 40-year period. To account for the time value of money (e.g., initial dollars are more valuable than future dollars) the present value of costs were calculated using interest (discount) rates ranging from 2% to 14%.

Differences in the amount of shade provided by bus shelters and trees over time was normalized by calculating the annual cost of shade on a per sq ft basis as follows:

$$CS = TC/TS \tag{6}$$

where

CS = cost of shade ($/sq ft)

TC = total costs for trees or bus shelters ($)

TS = ground projection of all trees or total surface area of bus shelter walls and roofs (sq ft)

The shade cast by metal shelters was assumed to be 152 sq ft per shelter, the maximum area if the roof and all side panels are installed.

Results

Bus Stop Survey, Projected Tree Numbers, and Leaf Area, Eighty-eight unsheltered bus stops were surveyed along Route #8 and 64 (73%) were suitable for planting (Table 3). The model simulated initial planting of 64 trees with a nearly equal distribution among the three types of locations (Table 3). A loss rate of 48% (31 trees) was projected for the 40-year period (Table 3 and Figure 2). Mortality rates were greatest for Fair sites (63%) and least for the Excellent sites (35%). Thus, to maintain one tree per bus stop over the

Table 2. Projected average annual mortality rates for each 5-year time period (%)

Locations	1993	1998	2003	2008	2013	2018	2023	2028
Excellent								
Type A	2.0							
Type B	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Type C							0.5	1.0
Total	2.75	0.75	0.75	0.75	0.75	0.75	1.25	1.75
Good								
Type A	4.0							
Type B	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Type C						0.5	1.0	2.0
Total	5.0	1.0	1.0	1.0	1.0	1.5	2.0	3.0
Fair								
Type A	6.0							
Type B	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Type C					0.5	1.0	2.0	3.0
Total	7.25	1.25	1.25	1.25	1.75	2.25	3.25	4.25

Table 3. Bus stop survey data and projected tree mortality

Locations	*Unsheltered bus stops*	*Tree shelters installed 1990*	*Total tree losses*	*% Tree losses*
Excellent	23	23	8	35
Good	22	22	11	50
Fair	19	19	12	63
Unsuitable	24	---	---	---
	88	64	31	48

40-year period, 95 trees were projected to be planted. Total leaf area (including the contribution of replacements) increased gradually as the trees matured, then stabilized, and finally decreased slightly due to increased senescence-related mortality (Figure 2).

Projected Costs. Projected total costs were over twice as great for the metal shelters than for trees (Table 4). Average annual costs per bus stop were projected to range from $114 for TFT/GR trees to $251 for shelters. Savings for the TFT/GR and Contract scenarios were projected to be $350,351 (55%) and $341,876 (53%), respectively.

In both tree planting scenarios the present value of costs were less than for shelters at all discount rates (2-14%). Assuming a discount rate of 7%, the present value of cost savings for the TFT/GR and Contract scenarios was $203,742 (62%) and $196,498 (60%) (Table 4). Relatively greater initial costs for installation of the shelters accounts for increased percentage savings for trees when comparing the present and future value of total costs (Figure 3). Figure 3 illustrates the projected 40-year stream of costs and periodic cost-jumps due to installation and replacement of shelters and the 5-year pruning cycle for trees.

Cost-Effectiveness of Shade. Because trees were projected to provide less shade initially than shelters, they were less cost-effective during the first 15 years (Figure 4). However, over the 40-year planning horizon trees were more cost-effective than metal shelters (Table 4). Total savings were projected to be $4.08/sq ft (21%) for the TFT/GR scenario and $3.93/sq ft (20%) for the Contract scenario. Average annual cost savings for the trees was $0.10/sq ft.

Projected Tree Planting and Maintenance

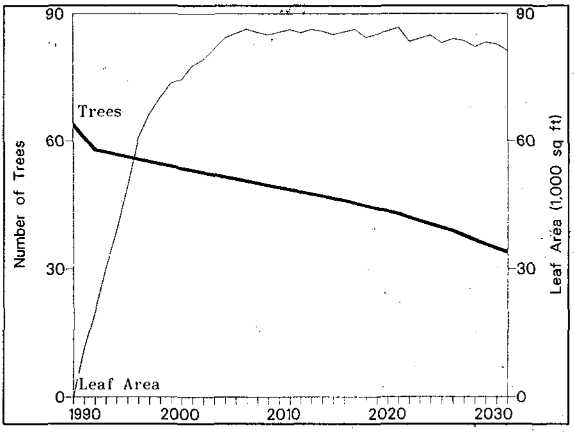

Figure 2. Projected tree numbers for the initial planting of 64 trees in 1990 shows the time-dependent effects of mortality on the population. The projected total leaf area curve includes the contribution of replacements.

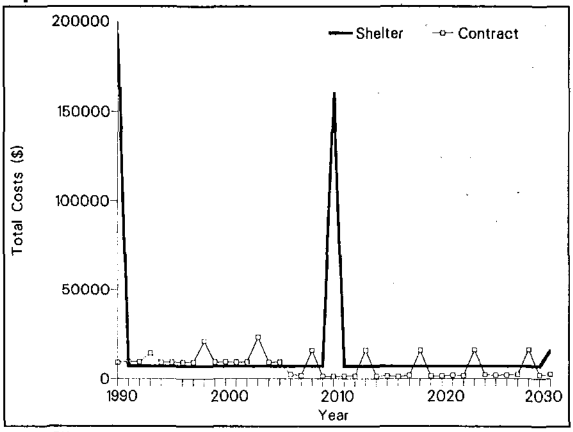

Figure 3. The projected annual costs for shelter and trees (Contract scenario) shows periodic cost-jumps due to shelter installation and replacement and the 5-year pruning cycle.

Costs. Water costs were the single greatest expense, accounting for 61% ($177,750) and 60% ($180,050) of total costs in the TFT/GR and Contract scenarios, respectively (Table 5). On average for all locations, annual irrigation costs were projected to be about $70 per tree. The second largest expense was for pruning, representing 35% and 34% ($102,969) of total costs in the TFT/GR and Contract scenarios. Average annual costs for pruning were $40 per tree. Removal costs accounted for 3% ($8,896, $3.48/yr/tree) of total expenses in both scenarios. Planting costs also accounted for 3% of total costs in the Contract scenario ($9,025, $3.53/yr/tree), but 1%

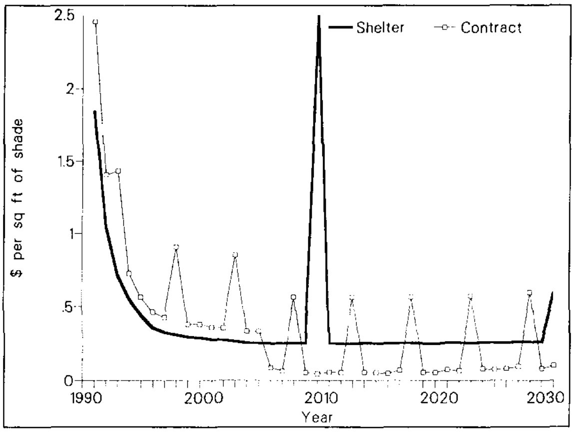

Figure 4. During the first 15 years shade from shelters was more cost-effective than shade from trees due to the smaller size of trees and greater costs for planting and irrigation. During the final 25 years trees were more cost-effective than shelters.

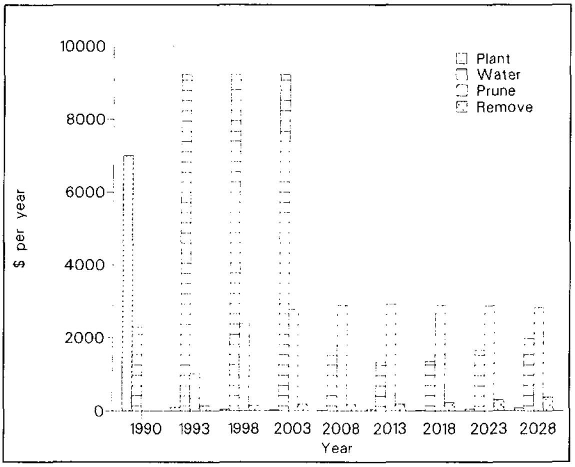

Figure 5. Projected average annual costs for the Contract scenario illustrates the initial importance of planting and irrigation costs and subsequent importance of pruning and removal costs.

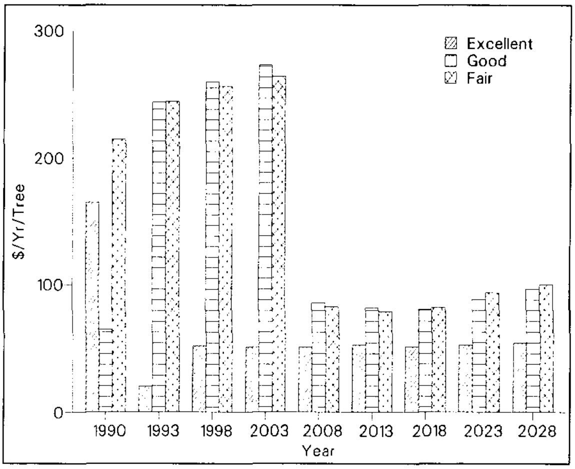

Figure 6. Projected average annual costs per tree for the Contract scenario shows the magnitude of savings associated with planting in more suitable sites.

($2,850, $1.11/yr/tree) in the TFT/GR scenario because expenses only accrued for pavement removal.

Projected tree costs were substantially greater during the first 15 years than thereafter due to initial planting and irrigation expenses (Figure 5). The average annual costs for planting and watering replacements decreased from 2003 to 2018 and then gradually increased as more trees died. The effects of higher senescence-related mortality rates is also seen in growing removal costs from 2018 to 2028. Average annual pruning costs were projected to increase as the trees matured and then declined slightly as large old trees were replaced at an increasing rate.

Although more trees were planted at locations designated Excellent than at other sites, total costs were considerably less because irrigation

Table 4. Projected costs for three scenarios ($)

Scenario	*Total costs*	*Present value of costs (7%)*	*Ave. annual cost*	*Ave. ann. cost/ bus stop*	*Cost-effectiveness $/sq ft*	*Cost-effectiveness $/sq ft/yr*
Shelter	642,816	328,479	16,070	251	19.54	0.489
TFT/GR	292,465	124,737	7,312	114	15.46	0.386
Contract	300,940	131,981	7,524	118	15.61	0.390

Table 5. Projected costs by location for the contract scenario

		Planting		Irrigation		Pruning		Removal		All Costs	
Location	# trees	Total cost	$/yr /tree	Total cost	$/yr /tree	Total cost	$/yr /tree	Total cost	$/yr /tree	Total cost	$/yr / tree
Exc.	23	2,015	2.19	2,300	2.50	41,249	44.84	2,630	2.86	48,194	52.39
Good	22	2,145	2.44	93,150	105.85	35,904	40.80	3,264	3.71	134,464	152.80
Fair	19	4,865	6.40	84,600	111.32	25,816	33.97	3,002	3.95	118,283	155.64
All	64	9,025	3.53	180,050	70.33	102,969	40.22	8,896	3.48	300,940	117.55

was provided free by adjacent businesses. On an average annual per tree basis, total costs for the Excellent sites ($52.39/yr/tree) were projected to be about one-third the costs for the Good ($152.80/yr/tree) and Fair ($155.64/yr/tree) sites in the Contract scenario (Table 5). Trees at Fair sites had the highest costs on an average annual per tree basis for planting, irrigation, and removal. Greater mortality resulted in the need for more tree removal and irrigation of replacements. However, pruning costs were least at Fair sites because the replacements had less leaf area than the mature trees they supplanted. When considering the stream of costs by location, trees at Fair locations were projected to be most expensive initially and later in the project due to greater planting costs and mortality at these times (Fig. 6).

The projected average annual expenditure of $117.55 per tree is considerably greater than the national and west regional means of $10.62 and $13.11, respectively, as reported for street trees by Kielbaso (2). This discrepency can be explained by the unusually high costs for "retrofit" irrigation and the relatively short pruning cycle simulated in this study.

Discussion

These findings suggest that shade from trees at bus stops can be an economic substitute for shade provided by metal shelters in hot-climate cities such as Tucson. This conclusion is supported by the fact that both the future and present value of tree costs were less than half the cost of shelters. Therefore, minor changes in important modeling assumptions, such as mortality rates, installation and maintenance costs, or discount rates are not likely to alter the findings significantly. Planting of the trees by TFT/GR volunteers reduced total costs by only 3% compared to the Contract scenario. However, findings from other studies (5, 9) indicate that public involvement in tree planting can reduce vandalism and mortality, a factor not accounted for in this study. Similarly, pruning costs could be reduced if well-trained volunteers pruned bus stop trees in their neighborhoods, at least while the trees were relatively small. Because irrigation was the single greatest tree cost, efforts to enlist adjacent businesses to Adopt-A-Bus Stop and connect their trees to existing landscape irrigation are warranted. Also, irrigation costs could be substantially lower when designed as part of bus stop landscaping for new roadside improvement projects as opposed to the retrofit of existing bus stops. Trees planted with the construction of each new shelter could eliminate the need to replace old shelters 20 years after installation, and remaining slabs could support new benches, trash receptacles, and lighting.

Although trees at bus stop can be less expensive than shelters, it is appropriate to recognize the limitations of this analysis and the applicability of its results. The costs of installing and maintaining bus shelters and trees were based on information obtained from a survey of local officials, landscape contractors, and arborists. These costs will undoubtedly vary from city to city. Costs for disease and pest control were not included because most desert-adapted trees are resistant to these problems. Similarly, other tree care expenses were omitted because of infrequent use and limited cost.

Costs for trash pick-up were assumed to be the same for the metal shelters and trees because mesquite leaflets and flowers are too small to rake. Sun Tran budgets $145 annually for trash pick-up at each stop, and this expense could be relatively greater for tree planting scenarios if other tree species were used. Although some liability and public health costs (e.g., property damage, legal work, allergies from pollen) could accrue as a direct result of tree planting, these types of expenditures are difficult to quantify and thus were not considered. Finally, this analysis assumed that all bus shelters were removed and not replaced in the year 2030, the end of their second 20-year life cycle. However, trees that died at this time were replaced and all bus stops were assumed shaded at 2030 in the planting scenarios.

Although this analysis focused on the ability of trees to provide cost-effective shade, trees may not provide other important functions at bus stops. For instance, night lighting and signage are more easily attached to a shelter than a tree. Trees may not provide as much protection from rain and low angle sunlight as do the walls of bus shelters. In cold or rainy climates bus shelters may be totally enclosed and equipped with heaters. Clearly, trees will not function as effectively as shelters under these climatic conditions. Alternatively, bus shelters do not provide environmental and aesthetic benefits equivalent to trees. Benefits associated with trees were not monetized here, but a previous study that simulated planting of 500,000 trees in Tucson found that for every $1 spent to maintain trees, $2.62 of benefits were returned from air conditioning energy savings, dust reduction, and stormwater runoff interception (4).

Although the results of this study are primarily of regional value, it has demonstrated the utility of life-cycle costing as an urban forest planning and management tool. Additionally, it has contributed to the initiation of an Adopt-A-Bus Stop program in Tucson that involves Sun Tran, Trees for Tucson/ Global ReLeaf, and local businesses and neighborhood groups. On Earth Day, 1991, each city council member will plant a bus stop tree in his or her ward to kick-off the program. Similar programs are likely to be economically feasible in other midlatitude cities where shade is the primary function of bus stop shelters.

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Résumé. L'ombrage aux arrêts d'autobus peut rehausser le confort thermique des voyageurs en attente et peut encourager de nouveaux usagers, réduisant de ce fait la pollution de l'air et la congestion de la circulation. Cette étude emploie une simulation d'ordinateur pour comparer l'effet de coût de l'ombrage fourni par les arbris métalliques versus par les arbres à 64 arrêts d'autobus de Tucson en Arizona. Les valeurs projetées totales, présentes et futures, de coûts des 40 prochaines années étaient de 50% supérieures pour les abris que pour les arbres. Quand les différences dans la densité d'ombrage fournie dans le temps étaient considérées, des économies de coûts de 20% étaient projetés pour les arbres. Les frais d'arrosage et délagage s'estimaient à environ 95% de tous les coûts projetés des arbres. Ces concusions suggèrent que les arbres peuvent être un substitut de coût positif face aux abris aux arrêts d'autobus dans les villes de latitude moyenne où l'ombrage est utile.

Zusammenfassung: Baumschatten an den Bushaltestellen können den thermalen Komfort wartender Busfahrgäste steigern und sogar neue Fahrgäste anlocken um dadurch Luftverschmützung und Verkehrsstauungen zu reduzieren. Diese Studie wurde mit der Hilfe einer Computer-Vorspiegelung ausgeführt um bei 64 Bushaltestellen in Tucson, Arizona die Kostenwirksamkeit zwischen Schatten von metallen Schutzdächern und Baumschatten zu vergleichen. Der vierzigjährige Entwurf für die Gesamtkosten war 50% höher für Schutzdächer als für Bäume. Als Unterschiede für die Gesamtschattenflecken mithineinbezogen waren, wurde bei den Bäumen die Kosten 20% weniger. Die Bewässerungs- und Auslaubungskosten erledigen 95% aller entworfenen Baumkosten. Diese Ergebnisse deuten an, dass Bäume eine kosten-wirksame Ersetzung für metalle Schutzdächer bei Bushaltestellen in Städten mittlerer Breite sind.

EFFECTS OF A DEEP LAYER OF MULCH ON THE SOIL ENVIRONMENT AND TREE ROOT GROWTH[1]

by Gary W. Watson and Gary Kupkowski

Abstract. After two years, no detrimental effects were found from application of 0.45 m (18 in) of wood chip mulch over soil in which the roots of trees were growing. Soil temperature, moisture and oxygen diffusion rate (ODR) were similar to soil without mulch. Root density in mulched soil was not different from unmulched soil; additional roots had proliferated into the mulch.

Wood chip mulch is commonly used as a 'soft surface' to prevent personal injury in playgrounds. Many of these playgrounds are built near established shade trees. There is concern that roots could be damaged, because often, more than 45 cm (18 in) of wood chips are placed over the surface of soil containing roots. Most tree roots are very near the soil surface. The oxygen required by roots must enter through the soil surface, and any material covering the soil surface can interfere with the supply of oxygen.

The benefits of applying mulch approximately 10 cm (4 in) deep, for normal landscape uses are well documented (4). Under mulch, soil moisture is conserved, and temperature extremes are moderated. Root development is increased in the improved soil, and in the mulch itself (12).

The negative effects of mulch are not as well understood (4). Excessively deep mulch could potentially damage roots by reducing soil aeration. Rapid decomposition of the wood chips could produce excessive heat, or create a nitrogen deficiency from increased microbial activity.

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