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ORGANIZING PLANT MATERIALS IN RESIDENTIAL LANDSCAPES USING CITYGREEN®

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Abstract. **Traditional and contemporary residential landscape designs representing different levels of plant diversity and spatial arrangement were evaluated for their values of carbon storage and sequestration, air pollution removal, stormwater runoff control, and home energy savings using CITYgreen®. Despite some shortcomings, CITYgreen® showed potential application in evaluating landscape designs. Decision matrices combined with weighting summation procedures offer homeowners a means to compare alternative landscape plans more objectively. The technique is explained and demonstrated with the use of a hypothetical example.**

Residential landscapes are normally designed for aesthetics. While aesthetics is an important consideration in residential landscape design, it is not the only one. Other functions such as cooling in the summer, allowing the sun's warmth to heat in the winter, blocking winds, sheltering from rain or snow while controlling the drainage of surface water, and to providing colors and fragrances, are all important but often de-emphasized in favor of appearance.

Landscaping is becoming widely regarded by homeowners, not as a luxury, but as a valuable investment that increases property values significantly. Based on a nationwide survey of realtors, returns on investment of landscape expenditures range from 15-20 percent (ANLA, 2002). More importantly, homeowners are increasingly aware and knowledgeable of functional values of landscaping other than aesthetics.

For example, properly designed, installed, and maintained residential landscapes can result in savings on utility bills. Perhaps the most important contribution of landscaping is the sensory perception people experience and not the return value on their investment. Spaces made useful, comfortable, relaxing, and stimulating contribute to quality living.

The changing perception of homeowners and better understanding of the many benefits of landscaping has helped boost the landscaping industry during the past several years (ANLA, 2002). The homeowners' improved perceptions could also be attributed to the popularity of landscaping television shows, proliferation of how-to-do books, and the advent of computerized landscape design software. Generally, however, these tools lack two important elements. First, the lack of transparency of the process to homeowners. Second, they do not provide the ability to evaluate the contribution of the design prior to installation. This often leaves the homeowners wondering about the non-aesthetic benefits of the landscape design. An integrated approach combining the use of commercial design software and geographic information system (GIS) technology could provide this additional information.

Landscaping involves the spatial and temporal arrangement of various plant materials and non-living components (Motloch, 2001). The species composition and arrangement determines the quantity and quality of benefits generated. The software program CITYgreen® was used to generate scenarios of several designed residential landscapes and the benefits associated with each scenario. A procedure was then adapted to help make decisions in which designed residential landscape scenario would optimize preferred benefits.

CITYgreen® is a computer program developed by American Forests (2002). In conjunction with ArcView GIS®, CITYgreen® provides tools to map, measure, display, and analyze the benefits of urban ecosystems. CITYgreen® enables users to evaluate, at regional and local levels how various landscapes affect carbon storage and sequestration, air pollution removal, stormwater management, and summer energy savings.

The objectives of this paper were (1) to quantify the contributions of designed residential landscapes for carbon storage and sequestration, air pollution removal, stormwater runoff control, and home energy savings, and (2) to demonstrate a weighting summation valuation technique for objectively comparing alternative landscape designs.

Materials and Methods

To achieve the first objective, a representative design of a residential landscape for north Florida was obtained (Gilman, 2004). The design was adapted to show a traditional design characterized by more lawn than paved areas, and placement of plant materials in front of the house (Fig. 1A), and a contemporary design with less lawn, more paved areas, and greater distribution of plant materials (Fig. 1B). The placement of plant materials and the general features of each design including percent area represented by lawn, shrubs, and hardscapes are summarized in Fig. 1. This information was then entered into CITYgreen® for the determination of carbon storage, carbon sequestration, air pollution removal, stormwater runoff control, and home energy savings.

To evaluate the effectiveness of a weighting summation valuation technique for comparing alternative landscape designs, two alternative landscape designs for a hypothetical north Florida residential home were also obtained (Gilman, 2004). Figure 2 shows comparisons of the two alternative designs' features.

Finally, the following required data by CITYgreen® were standardized for all cases:

Hydrologic Soil Group: A (Very Impervious)
Percent Slope: 5
Rainfall Type: II N Florida
Precipitation (24 hour): 6 inches
Energy costs: $1,000/year

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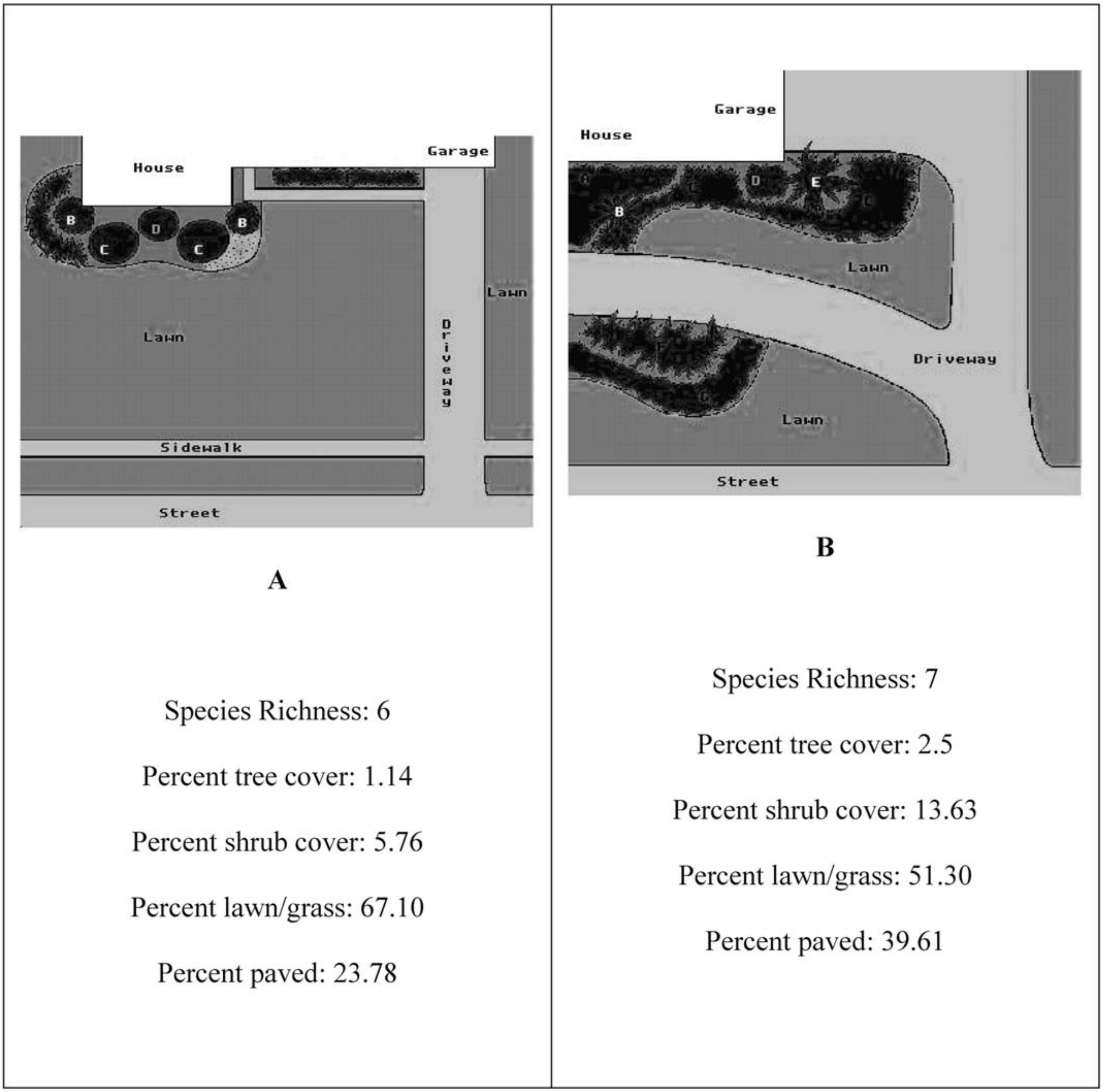

Fig. 1. General features of traditional landscape design (A) and contemporary landscape design (B).

Using the landscape design drawings along with CITYgreen® mapping and digitizing tools, features were delineated. These features, including property boundaries, trees, shrubs, lawns, buildings, and impervious surfaces (driveways and sidewalks) were digitized on screen and their respective attributes added into the database. Following data input, CITYgreen® statistics and analytical tools were used to evaluate the contributions of plants for each of the landscape designs to ecological services.

Results and Discussion

Valuation of the Benefits of Designed Landscapes Using CITYgreen®

Based on the standardized landscape designs, benefits were calculated and are summarized in Table 1.

Carbon Removal Benefits. This category includes carbon storage and carbon sequestration. The former represents the plants' capacity to store carbon. In contrast, the latter, refers to

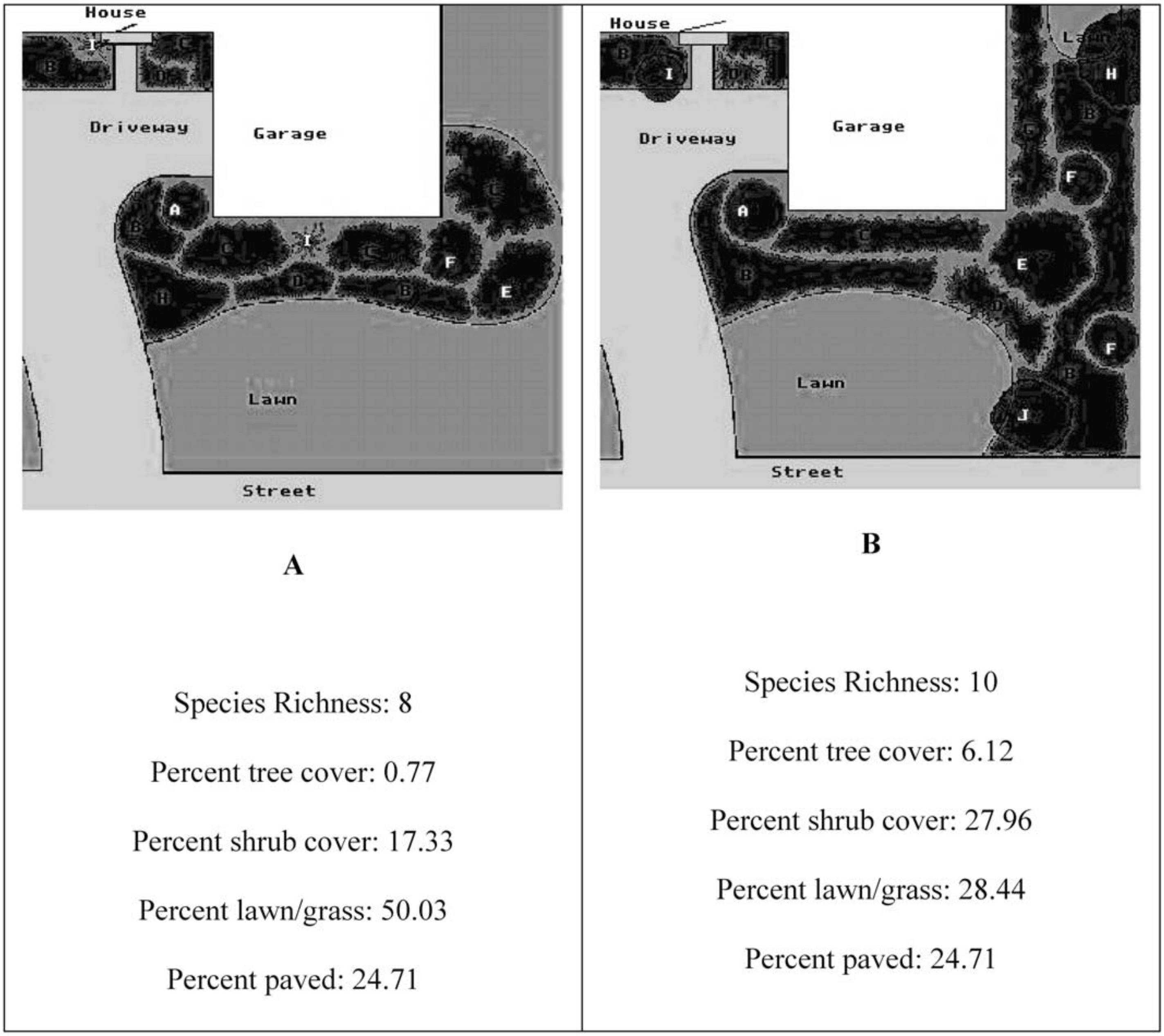

Fig. 2. Alternative landscape designs for hypothetical example.

the process of removing CO_2 from the atmosphere and converting it into stored compounds (Nowak and Rowntree, 1991).

Carbon storage is a function of canopy coverage and plant size distribution. The carbon storage varied greatly between the two landscape designs. The contemporary landscape design had greater amount of carbon storage at 24.60 t compared with traditional landscape design at 10.36 t. This was a result of greater canopy cover and plant size distribution in the contemporary landscape design. In addition, the contemporary landscape design had greater potential to store carbon since it included more tree and shrub cover.

Between the two landscape designs, the carbon sequestration difference of 0.04 t per year is explained by the presence of more young plants with smaller diameters in the contemporary design than in the traditional design. In general, the more young trees on a given landscape the greater the rate of carbon sequestration.

Air Pollution Removal Benefits. Plants provide air quality benefits by removing pollutants such as ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter less than 10 µm in size (PM_{10}), and carbon monoxide (CO) (McPherson et al., 1994). Air pollution removal had the greatest amount of savings. All dollar values were more beneficial for the contemporary design than for the traditional design.

Stormwater runoff control benefits. The stormwater runoff component of CITYgreen® is based on USDA Technical Release 55 (TR-55), Urban Hydrology for Small Watersheds, developed by USDA/NRCS to estimate stormwater runoff volume as well as percentage changes in time of concentration and peak flow. Traditional design had a total stormwater runoff reduction of

Table 1. Magnitudes of benefits associated with traditional and contemporary designs of residential landscapes in North Florida.

Benefit category	Traditional landscape design	Contemporary landscape design
Carbon removal benefits:		
Storage capacity (tons)	10.36	24.60
Sequestration rate (tons/year)	0.03	0.07
Air pollution removal benefits (lbs/year):		
O_3	7.73 ($23.73)	18.36 ($56.35)
SO_2	1.25 ($0.94)	2.96 ($2.23)
NO_2	2.56 ($7.87)	6.09 ($18.69)
PM_{10}	6.19 ($12.69)	14.70 ($30.13)
CO	0.53 ($0.23)	1.26 ($0.55)
Stormwater runoff control benefits:		
Runoff depth (in)	9.72	11.31
Time of concentration (hrs)	2.02	1.62
Peak flow (ft^3/sec)	9.47	13.09
Runoff volume (ft^3)	98,213.00	116,096.00
Storage required to mitigate (cu ft)	0.00	12,406.00
Home cooling benefits:		
Total tree savings ($)	128.20	16.00
Total roof savings	44.02	44.02
Total dollars saved	172.22	60.02
Total kwH saved	2,126.00	741.00
Carbon avoided (lbs)	77,514.00	27,015.00

9.72 inches and contemporary design had a total reduction of 11.31 inches. The difference in stormwater runoff reduction totals was due to dense vegetation in some areas. Time of concentration for both designs was also quite different. The percent slope within the study areas was not greater than 5 percent. The peak flow reduction ranged from 9.47 ft^3 sec^{-1} (traditional design) to 13.09 ft^3 sec^{-1} (contemporary design). The runoff volume was much higher in the contemporary design indicating that lawns are more adapted to water retention than trees.

Energy Savings. Energy savings were estimated using energy ratings developed by researchers and is documented by American Forests. The energy rating of each individual tree is based on five criteria: (1) azimuth and distance from a building structure, (2) height, (3) diameter at breast height (DBH), (4) plant species shade characteristics, and (5) shading of air conditioners or windows.

The total energy savings ranged from about $60 for contemporary design to about $172 for traditional design. The greater amount of savings is due to the amount of shading buildings receive from trees. Windows and air conditioners also play a factor in higher energy prices. The more mature trees with large crown coverage supply more shade. Another factor in energy savings is how close the trees are to the building.

A Decision Matrix and Weighting Summation Method for Comparing Alternative Landscape Designs

In its simplest form, a decision matrix is merely a way of showing the differences and similarities among alternatives. One of its many uses is to bring together and summarize the effects of different plans on a set of decision criteria. Decision matrices appear to be useful in evaluating and comparing alternative landscape designs, especially when combined with the weighting summation method of valuation. This paper demonstrates the technique using a hypothetical example.

The weighting summation method of comparative valuation has been used for comparing alternative sites for a manufacturing plant, solid waste disposal, or alternative power line locations (Hobbs, 1978; Leopold, 1969; Zieman, 1971). Derivation of accurate value weights is not easy and has been the subject of theoretical and applied research. Different weight scales can be used. A widely used technique involves assigning each decision criteria a numerical value from -10 to +10 reflecting its relative value (Zieman, 1971). Other techniques include allocating 100 points among the criteria reflecting the relative values. Whatever technique is used the weights should reflect the relative value, or importance, of each criterion to all others in the matrix. In this paper, we assigned each benefit a weight from -10 to +10 reflecting its value relative to the other criteria in the decision matrix. As indicated above, many different scales can be used for the weights. The range of -10 to +10 was comfortable for use in this example.

After assigning the weights, a scaling procedure is needed because of the different units by which each benefit is measured. Zieman (1971) discussed several techniques that can be used. In this paper, the Z score similar to regression analysis was used by calculating:

$$Z = (x_i - x_m) / s_x$$

where x_i = actual value of benefit i

x_m = average of all benefit values

s_x = standard deviation of the benefits data

The benefits determined in CITYgreen® for the two alternative landscape designs recommended for north Florida homes were calculated (Table 2). A choice can be made between the alternative designs by using an implicit set of values to compare the magnitudes of each benefit between alternatives. However, it is often useful to state the weight or value assigned to each benefit. Thus, the relative importance of each of the benefits such as carbon sequestration to air pollution removal or runoff reduction could be stated. This explicit statement adds transparency to the process and enables others to understand the basis on which a decision was reached. In addition, if the explicit weights are stated, they can be changed to reflect differing viewpoints among home residents.

Table 2. Decision matrix with unscaled benefit values/magnitudes and scaled z- values.

Benefit category	Unscaled values: Alternative design 1	Unscaled values: Alternative design 2	Mean unscaled values	Standard deviation	Scaled values (Z-scores): Alternative design 1	Scaled values (Z-scores): Alternative design 2
Carbon removal benefits:						
Storage capacity (tons)	19.98	6.90	13.44	9.25	0.71	-0.71
Sequestration rate (tons/year)	0.06	0.01	0.04	0.04	0.71	-0.71
Air pollution removal benefits (lbs/year):						
O_3	14.91 ($45.75)	6.28 ($19.26)	10.60	6.10	0.71	-0.71
SO_2	2.40 ($1.81)	1.01 ($0.76)	1.71	0.98	0.71	-0.71
NO_2	4.95 ($15.18)	2.08 ($6.39)	3.52	2.03	0.71	-0.71
PM_{10}	11.94 ($24.47)	5.03 ($10.30)	8.49	4.89	0.71	-0.71
CO	1.02 ($0.44)	0.43 ($0.19)	0.73	0.42	0.71	-0.71
Stormwater runoff control benefits:						
Runoff depth (in)	10.26	10.62	10.44	0.25	-0.71	0.71
Time of concentration (hrs)	1.81	1.71	1.76	0.07	0.71	-0.71
Peak flow (ft^3/sec)	10.44	10.67	10.56	0.16	-0.71	0.71
Runoff volume (ft^3)	96,721.00	98,297.00	97,509.00	1,114.20	-0.71	0.71
Storage required to mitigate (ft^3)	10,476.00	10,589.00	10,532.50	79.90	-0.71	0.71
Home cooling benefits:						
Total tree savings ($)	32.00	64.10	48.05	22.70	-0.71	0.71
Total roof savings	44.02	44.02	44.02	0.00	0.00	0.00
Total dollars saved	76.02	108.12	92.07	22.70	-0.71	0.71
Total kwH saved	938.60	1,334.90	1,136.75	280.23	-0.71	0.71
Carbon avoided (lbs)	34,217.00	48,664.00	41,440.50	10,215.57	-0.71	0.71

Table 2 also shows the Z scores for original values. Also included in this table are the means and standard deviations of the values for each benefit. The benefits associated with each alternative design were also compared by applying the weighting procedure described earlier (Table 3). Two different sets of weights were used: weight set #1 assigned equal weights to each benefit; weight set #2 valued carbon sequestration, air pollution removal heavily, runoff reduction, and energy sav-

Table 3. Decision matrix with weights and scores.

Benefit category	Weights set #1	Alternative design 1	Alternative design 2	Weights set #2	Alternative design 1	Alternative design 2
Carbon removal benefits:						
Storage capacity (tons)	5	3.54	-3.54	5	3.54	-3.54
Sequestration rate (tons/year)	5	3.54	-3.54	5	3.54	-3.54
Air pollution removal benefits (lbs/year):						
O_3	2	1.41	-1.41	5	3.54	-3.54
SO_2	2	1.41	-1.41	5	3.54	-3.54
NO_2	2	1.41	-1.41	0	0.00	0.00
PM_{10}	2	1.41	-1.41	0	0.00	0.00
CO	2	1.41	-1.41	0	0.00	0.00
Stormwater runoff control benefits:						
Runoff depth (in)	2	-1.41	1.41	5	-3.54	3.54
Time of concentration (hrs)	2	1.41	-1.41	3	2.12	-2.12
Peak flow (ft^3/sec)	2	-1.41	1.41	2	-1.41	1.41
Runoff volume (ft^3)	2	-1.41	1.41	0	0.00	0.00
Storage required to mitigate (ft^3)	2	-1.41	1.41	0	0.00	0.00
Home cooling benefits:						
Total tree savings ($)	2	-1.41	1.41	5	-3.54	3.54
Total roof savings	2	0.00	0.00	5	0.00	0.00
Total dollars saved	2	-1.41	1.41	0	0.00	0.00
Total kwH saved	2	-1.41	1.41	0	0.00	0.00
Carbon avoided (lbs)	2	-1.41	1.41	0	0.00	0.00
Weights set #1:						
Sum		4.24	-4.24			
Rank		1	2			
Weights set #2:						
Sum					7.78	-7.78
Rank					1	2

ings from trees and roof heavily and the rest unfavorably. At the bottom of the table are the summed, weighted scores of each landscape design. These were determined by multiplying the scaled value of a benefit by its weight and summing over all benefits in an alternative organization.

For example, with the first set of weights, Alternative Design 1 had a score of 4.24 and Alternative Design 2 scored—4.24. The decision rule to apply is to choose the design with the highest score. Thus, using weight set number 1, Design 1 would be chosen. The scores are meaningful only within a weight set. Scores for a given set of weights cannot be compared to scores obtained with other weights. Thus, the scores using weight set 2 are quite different from those using weight set 1. However, the same decision rule applies, namely, choose the alternative structure with the highest score.

The difference in ranking among the alternatives with different sets of weights is to be expected. Indeed, this is normal, even without explicit weights, when different people or groups with varying goals and value sets compare alternatives. The compact, explicit, numerical nature of the decision matrix used here facilitates sensitivity analysis and examination of what causes these differences. Furthermore, conflicting interest groups can focus on differences, identify areas for compromise, and eventually bring about agreement.

Conclusions

This paper has demonstrated the use of CITYgreen® in evaluating the values of benefits associated with different designed residential landscapes. Although, many of the finer points underlying the assumptions needed to effectively use CITYgreen® remain under scrutiny, the software program shows promise in this arena of landscape design research. Further refinement of the software, especially its plant database and its built-in functional relationships/models should include groundcovers and other widely used landscape plants.

Also, we have described the use of decision matrices and the weighting summation procedure as it might be applied to evaluating alternative designs of residential landscapes. The technique is simple, transparent and takes homeowners' non-aesthetic goals and objectives into account.

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