Effects of traffic on soil physical characteristics and vegetative resources of the NATIONAL MALL

G.B. Runion, H. H. Rogers, C. W. Wood, S. A. Prior, and R. J. Mitchell

SURROUNDED by the Capitol, the Washington Monument, the Smithsonian Institution and other museums, the National Mall is used as a recreational area by those who live and work in the metropolitan Washington, D.C. area and is a popular picnic and relaxation spot for tourists visiting the U.S. capital. In addition, the Mall is the site of a variety of national celebration events, demonstrations, and marches. The National Park Service (NPS) maintains the Mall and recently has been concerned that the intensity of use threatens the sustainability of this national resource. Compaction of urban soils, in general and specifically on the National Mall, has been a concern for some time *(4, 12, 13)*. It is noteworthy that the decision to use elm trees in this area was a fortuitous choice as elms are known to be more tolerant of poor soil aeration than many other tree species *(17, 18)* and should be better able to withstand higher levels of soil compaction.

The NPS is particularly concerned with special event traffic which occurs when large numbers of people visit the Mall during a short period of time for a scheduled event, such as the Smithsonian Institution's Festival of American Folklife. The NPS commissioned study on the effects of the 1989 Festival *(6)* reported significant degradation of groundcover vegetation and an increase in soil bulk density. The report concluded, "There is a need for a reduction or elimination of the impact on the Mall, especially large events that overwhelm the resources and the scale of the Mall." The report, however, was based primarily upon observational data. The lack of comparison of soil conditions before and after the Festival strongly reduced the ability to rigorously test the influence of the Festival on soil parameters.

In June 1991, researchers at the USDA's National Soil Dynamics Laboratory and Auburn University were asked by the Smithsonian to assess the impact of the 25th An-

PHOTO COURTESY OF JOHN SHORT, NATIONAL PARK SERVICE, CENTER FOR URBAN ECOLOGY, WASHINGTON D.C. USE OF THIS PHOTOGRAPH DOES NOT IMPLY AGREEMENT BY THE NATIONAL PARK SERVICE WITH THE CONCLUSIONS OF THIS REPORT.

Photograph of the National Mall taken from inside the Washington Monument. Panels in the center of the Mall contain grass, while panels on the left and right contain elm trees and groundcover (predominantly grass). All study panels were located on the Washington Monument end (bottom of photograph) of the Mall. Festival exhibits (high traffic) occupied the second and third left-hand and first right-hand elm panels; control plots (low traffic) were located in the first and second right-hand elm panels.

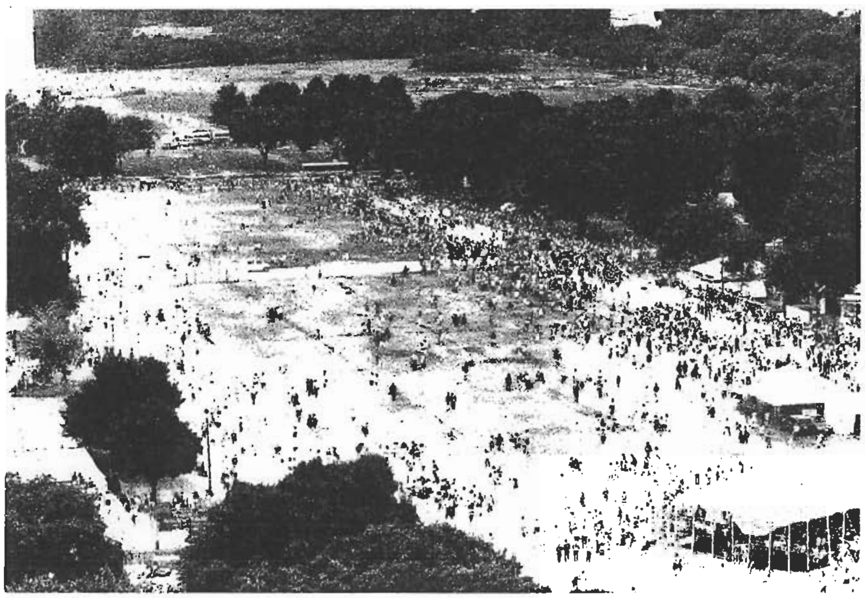
Reprinted from the *Journal of Soil and Water Conservation*
September-October 1993, Volume 48, Number 5

nual Festival of American Folklife, held June 28 to July 7, 1991, on the soil characteristics of the Mall. A second objective was to provide an assessment of the health of elm trees on the Mall.

Research methods

Plots were established within six panels on the National Mall; a panel is an area bounded by sidewalks and access roads containing trees and/or grass. Three of these panels were occupied by exhibits for the Smithsonian's festival and were designated as high traffic areas; the remaining three panels, all low traffic areas, did not contain Festival exhibits but were adjacent to Festival panels. Within each panel, six trees were arbitrarily selected as plot trees.

PHOTO COURTESY OF THE SMITHSONIAN INSTITUTION CENTER FOR FOLKLIFE PROGRAMS AND CULTURAL STUDIES.



Photograph of the National Mall showing pedestrian use during the 1990 Festival of American Folklife.

All plots were located due north of the selected trees and were established one-half the distance from the bole of the tree to the edge of its crown. A soil core taken at this distance served as plot center. Each plot was divided into four dual quadrats; two randomly selected quadrats were sampled prior to the Festival and the remaining two quadrats were sampled immediately following the Festival.

Two types of data were collected from each plot or plot tree: data were collected prior to the Festival to establish a baseline for any potential future work which may take place on the Mall; and comparative data were collected both before and after the Festival to assess the direct impact of the Festival on physical properties of the Mall soils.

Baseline data. Root length density, root dry weight density, soil texture and soil nutrient status were determined from two soil cores (3.8 x 20 cm) taken from each quadrat prior to the Festival. The diameter at breast height (dbh = 4.5 ft) of plot trees was measured and diameter growth per year was calculated by subtracting measurements made by the NPS in 1988 from our measurements in 1991. Each tree also was visually assessed for general health. Foliage was collected from each plot tree with a pruning hook, visually examined for signs and symptoms of insects and disease, and assayed for nutrient content. Relative chlorophyll content of elm leaves was determined with a chlorophyll meter. Soil texture, soil element, and elm leaf element data were summarized and means with associated standard errors and ranges determined.

Comparative data. Bulk density, saturated hydraulic conductivity, and soil water content were determined using standard techniques *(3, 8)* from three soil cores at each sampling period. Six penetrometer measurements *(1)* were taken at four depths (0, 3.5, 7.0 and 10.5 cm) in each quadrat at both sampling dates.

Results and discussion

Diameter growth of plot trees was similar (1.79 ± 0.15 and 1.78 ± 0.15 cm yr^{-1} for high and low traffic areas, respectively) for the two traffic areas, indicating trees in the two areas are in similar states of health and vigor. Because some of the areas without Festival exhibits in 1991 (low traffic) may have contained exhibits in prior years, while the opposite may be true for the high traffic areas, the assignment of traffic load on these panels is likely to be unreliable in regard to traffic patterns that existed in the past. Nevertheless, an average diameter growth of 1.8 cm yr^1 for trees averaging ≈ 50 cm dbh indicates healthy and vigorous growth.

Plants need proper nutrition to function and grow. Nutrient deficiency can cause symptoms of abiotic disease and can predispose plants to infection by fungi and bacteria *(10)*. The most serious threat to mature trees in urban environments is from decline (a gradual, general deterioration of the tree caused by the interaction of abiotic and biotic factors) with inadequate nutrition one predisposing factor in the cause of declines *(10)*. The mean concentration of all major elements in elm foliage (Table 1) were similar to standard values *(5)*, which supports the diameter growth data (i.e., indicates that the trees are in a state of good health). Although the implications of the relative chlorophyll readings (mean = 42.4; range = 33.5-50.2) for nitrogen nutrition or elm health have not been determined, these data provide a basis of comparison for future readings taken on these trees. Future chlorophyll readings should be taken when the elms are in a similar phenological state to allow for comparison.

The visual assessment of tree health conducted prior to the Festival demonstrated that most plot trees were in good health and that the overall condition of trees in the two traffic areas was similar. Dutch Elm Disease is a prevalent and serious problem of American elms *(Ulmus americana L.)* throughout their range and has virtually eliminated elms from many urban environments *(15)*. The disease is present in the elm population on the National Mall; however, no signs or symptoms of this disease were noted on any plot trees. Mechanical injury, most often due to pruning or other maintenance efforts (i.e., cable anchors for branch support), was observed; however, most pruning wounds exhibited vigorous callus formation which again, indicates good health of the elms.

Most plot trees in both traffic areas had full crowns without symptoms of nutrient deficiency or decline. Black leaf spot, one of the most important foliar diseases on elms in North America *(15)*, was observed on 10 of the 36 plot trees and was considered extensive enough to cause some defoliation. Numerous types of other disease (i.e., leaf spots probably associated with elm leaf scorch and elm mosaic virus) and insect damage occurred on a few plot trees but were not considered severe.

No statistical differences in fine root length density (21.2 ± 2.3 and 24.5 ± 2.0 km m^{-3} for high and low traffic areas, respectively) or fine root weight density (0.40 ± 0.05 and 0.45 ± 0.05 kg m^{-3}) existed between the two traffic areas. It is not known if these fine root densities represent good, average, or poor quantities for elm trees; however, the data provide a baseline to track changes in fine root density over time.

The soils on the National Mall are Udorthents, which are made up of heterogenous, earthy fill materials *(14)* and are described in detail by Short *(13)*. Analysis of the nutrient status of soils taken from plots prior to the Festival demonstrated typical mean values and ranges for most elements and indicate adequate soil fertility. None of the major elements or micronutrients was considered limiting and the lead concentration was considered nontoxic. The electrical conductivity analysis (mean = 0.63; range = 0.24-0.89) indicated that soil salt levels would not be toxic or detrimental to plant growth. The pH range observed (mean = 6.8; range = 6.3-7.5) is nearly ideal for growth of a variety of plant species.

Soil particle size data collected prior to the Festival (44.9 ± 1.4 percent, 44.7 ± 1.2 percent and 10.4 ± 0.3 percent for sand, silt, and clay, respectively) indicate that 24 of the soils were classed as loam, four as sandy loam, and the remaining eight as silt loam. In general, these are medium-textured soils and are all adequate to support good plant growth.

Table 1. Concentration of elements in leaves of 36 elm trees on the National Mall in Washington, D.C.

Element*	Mean Concentration	Standard Error	Range	Standard Value†
	($g\ kg^{-1}$)			
N	29.10	0.50	22.50-37.90	15.00
K	12.27	0.46	6.81-17.96	15.00
Mg	3.00	0.10	1.60 - 5.02	2.60
P	1.90	0.05	1.14 - 2.36	2.00
Ca	15.14	0.61	9.92-24.76	17.50
	($mg\ kg^{-1}$)			
Cu	9.7	0.5	4.7 - 18.7	25.0
Fe	254.1	10.1	165.6-458.7	500.0
Mn	154.0	12.0	48.3-310.7	80.0
Zn	20.5	1.0	10.3 - 39.9	50.0
B	86.5	5.9	42.3-233.0	80.0
Mo	0.5	0.1	0.0 - 2.3	NA
Pb	2.7	0.6	0.0 - 10.2	NA

* N and C determined using LECO procedures; all other elements determined using ICAP procedures.

† Standard values from Cannon (5); (NA = not available)

Soil texture classification and concentrations of elements in our analyses were similar to those reported by Short *(13)*. However, we did not observe a large amount of variability in the concentration of elements or in the soil texture classification, which does not agree with the detailed findings of Short *(13)*. The most likely explanation for these discrepancies is that our analyses were from the top 15 cm of soil from a limited area of the National Mall while Short *(13)* collected soils by horizon from the entire Mall.

Soil bulk density is the ratio of soil mass to the bulk volume of the soil. Saturated hydraulic conductivity is a measure of the ability of the soil to transmit water. These factors are of considerable importance to plant growth. Root growth (as influenced by water and nutrient movement), root penetration, movement of water to drains and wells, and evaporative loss of soil water are but a few of the important influences that these two properties have on urban soils *(11)*. A wide range of values for bulk density and saturated hydraulic conductivity were found in both traffic areas at both sampling dates. The bulk density measurements in this study were considerably lower than those reported in the past *(6, 12, 13)*. This discrepancy could be due to the use of different techniques and soil from differing depths. It is also possible that cultural practices on the Mall have improved the physical condition of the soil to some degree. The average bulk density of our samples was around 1.30, a value considered nearly ideal *(12)*. Saturated hydraulic conductivity values averaged 3.4 m day^{-1}, which is considered normal for medium textured soils *(9)* such as those on the National Mall.

The saturated hydraulic conductivity of samples from both traffic areas increased during the time of the Festival (pre-Festival means = 2.3 and 3.0 m day^{-1} for high and low traffic areas, respectively; post-Festival means = 4.3 and 4.0 m day^{-1}). However, this soil parameter was highly variable (standard errors 0.5 m day^{-1}) and the increase is considered biologically insignificant, since mean values before and after the Festival fall within the range considered normal for medium textured soils *(9)*. There was no significant difference in the increase in saturated hydraulic conductivity between the two traffic areas, suggesting that Festival traffic had little impact on water infiltration into Mall soils.

Mean bulk density decreased in the low traffic area (means = 1.31 and 1.29 g cm^{-3} for pre- and post-Festival samples, respectively) but increased in the high traffic area (means = 1.34 and 1.35 g cm^{-3} for pre- and post-Festival samples, respectively) during the Festival, which resulted in a significant difference between traffic treatments after the Festival. The most likely explanations for the decreased bulk density in the low traffic areas are small sample size and large sample variability. These data indicate that there was very little change in bulk density during the time of the Festival for either traffic area. Also, the biological implications of any differences are considered negligible as the mean value for both traffic areas was within the range considered ideal for plant growth *(12)* at both sampling dates.

Cone penetrometers are widely used for testing soil strength in situ and have been used to study soil compaction *(1)*. Penetrometer resistance increased between the pre- and post-Festival samples for both traffic areas. Differences in penetrometer resistance cannot be attributed to differences in soil water content as percent soil water content (mean = 15.4 percent) was not significantly different between the two traffic areas at either sampling date nor between sampling dates. Prior to the Festival, the high traffic area had greater penetrometer resistance at 0, 7.0, and 10.5 cm depths compared to the low traffic area. This could indicate a difference in the normal condition of these areas, but was likely a result of, or at least influenced by, Festival activities which occurred prior to our assessment. Penetrometer resistance increased in both traffic areas during the Festival period, but the two traffic areas differed only at the 10.5 cm depth after the Festival. Thus, the soil was significantly more resistant to penetration (higher in strength implying higher compaction) after the Festival in both areas but the effect of traffic, at most soil depths, was negligible. Due to the close proximity of the high and low traffic panels, it is likely that all panels were affected by traffic that occurred as a result of the Festival and the assignment of a low traffic condition to some panels did not accurately reflect their condition during the Festival. It is not known why this difference in penetrometer resistance was not reflected by the bulk density or saturated hydraulic conductivity data.

Summary and conclusions

The results of this study, and consequently conclusions drawn from them, are subject to several limitations. First, we arrived on the Mall after many of the Festival exhibits had begun to be assembled and some damage to the soil may have taken place prior to initiation of the study. Second, the low traffic areas, while not directly associated with Festival exhibits, may have been impacted by special event traffic due to their proximity to the Festival panels. Finally, changes in penetrometer data between sampling dates was not reflected by differences in bulk density and saturated hydraulic conductivity. Assessment of the impact of a single special event, although informative, will provide only limited data on the overall anthropogenic degradation of the Mall resources. The National Mall is, in essence, the nation's front lawn, and rigorous, long-term evaluation and research are required to determine its best use and management.

Based on data from this study, we found little evidence to suggest a significant impact of the Festival on the soil or elm trees on the National Mall. Temporary damage to groundcover vegetation was observed but was not quantified. There was a slight increase in bulk density as a result of the Festival; however, this would not be biologically significant given that final bulk density values were still in a range considered near ideal for plant growth *(12)*. It has been shown that, for tilled soils, the majority of bulk density change occurs during the first pass of a vehicle *(16)*, and that this relationship is dependent on soil water content *(7)*. Although the Mall soils are not tilled, it is possible that the majority of compaction of Mall soils has already taken place and further compaction by additional use will be minimal, unless the soils are extremely wet during periods of intense use. There was an increase in penetrometer resistance during the Festival period, but this increase occurred outside, as well as inside, the area occupied by the Festival.

The elms on the Mall are currently in a state of good health. The baseline data provide a means of tracking changes in the health of these trees, a task that should be conducted if sound conclusions concerning anthropogenic impacts on these trees are to be made. Given the healthy state of the elms and the fact that any damage to the groundcover vegetative resource can be repaired, it appears that the NPS has the capability to maintain the Mall in a state of good health and high aesthetic quality despite heavy casual and special event traffic that impact this area. The question of whether or not to restrict casual and/or special event uses of the Mall therefore seems to be not one of biology, but one of management philosophy and economics. This conclusion seems to be supported by the report by Craul *(6)* who states, "The Mall landscape is not conducive to withstanding the impact of intense use without the equal amount of maintenance effort and funding."

Recommendations

Studies to assess the impact of casual and special event use of the Mall should be continued and should be more scientifically rigorous than those which have occurred to date. These studies should be conducted cooperatively by the NPS, Smithsonian Institution, USDA, and other interested scientists. Data from studies conducted on the Mall would be applicable to other urban parks and should help curators of these parks maintain aesthetic quality and resource health under intense public use by improving resource management.

A set of specific guidelines should be developed to minimize impact on the Mall's resources without compromising its use during important events. For example, timing event preparation to coincide with weather conditions (when soil is relatively dry) should lessen compaction effects. Roadways (i.e., metal or wooden mats) should be laid across panels when repeated vehicular traffic associated with special events is required. Trees should be closely monitored and managed (watered, fertilized, and pruned) with attention to avoiding stress, which would alleviate predisposition to disease. Construction techniques used during special events should keep impact on the Mall resources to a minimum. Again, these guidelines would be applicable to other intensely utilized urban parks.

A method of nondestructive aeration of the soil could be evaluated for use around the elm trees on the Mall. This aeration method, which has been used for below-ground fertilization, involves the use of an air compressor that drives air underground via an attached metal tube. The system has been used successfully by John Lesenger *(personal communication)* at the Alabama Shakespeare Festival to lessen the effects of soil compaction after the Alabama Highland Games and other activities on this site.

Use of a system of mesh elements placed in the soil has lessened the degradation of sports fields *(2)*. Perhaps using such a system could provide an increase in stability, reductions in degradation, and subsequent decreases in maintenance costs for the turf panels on the Mall. To avoid elm root damage, mesh materials could only be installed at very shallow depths or when elm trees are replaced.

REFERENCES CITED

1. Anderson, G., J.D. Pidgeon, H.B. Spencer, and R. Park. 1980. *A new hand-held recording penetrometer for soil studies.* J. Soil Sci. 31:279-296.
2. Beard, J. B., and S. I. Sifers. 1990. *Feasibility assessment of randomly oriented, interlocking mesh element matrices for turfed root zones.* In: R.C. Schmidt, E.F. Hoerner, E.M. Milner, and C.A. Morehouse, (eds.) *Natural and Artificial Playing Fields: Characteristics and Safety Features.* Amer. Soc. Testing & Materials, Standard Tech. Pub. 1073. pp. 154-165.
3. Blake, G. R. 1965. *Bulk density: core method.* In: C.A. Black, (ed.), *Methods of Soil Analysis.* Amer. Soc. of Agron. Madison, WI. pp. 375-377.
4. Bullock, P. and P.J. Gregory. 1991. *Soils: A neglected resource in urban areas.* In: P. Bullock and P.J. Gregory (eds.), *Soils in the Urban Environment.* Blackwell Scientific Publications, London. pp. 1-4.
5. Cannon, T. F. 1956. *Foliar analysis as an index to the fertilizer requirements of some ornamental trees.* Proc. Natl. Shade Tree Conf. 32:84-93.
6. Craul, P. J. 1990. *The condition of the soil and vegetation of the national Mall.* A report to the U.S. Dept. of the Interior, Nat. Park Serv., Natl. Capital Region.
7. Glinski, J., and J. Lipiec. 1990. *Soil Physical Conditions and Plant Roots.* CRC Press, Inc., Boca Raton, FL.
8. Klute, A. 1965. *Laboratory measurements of hydraulic conductivity of saturated soil.* In: C.A. Black, (ed.), *Methods of Soil Analysis.* Amer. Soc. of Agron. Madison, WI. pp. 210-220.
9. Klute, A.,and C. Dirkson. 1986. *Hydraulic conductivity and diffusivity: Laboratory methods.* In: A. Klute (ed.), *Methods of Soil Analysis. Part 1, 2nd ed.* Amer. Soc. of Agron. Madison, WI. pp. 771-798.
10. Manion, P. D. 1981. *Tree Disease Concepts.* Prentice-Hall, Inc., New Jersey.
11. Mullins, C. E. 1991. *Physical properties of soils in urban areas.* In: P. Bullock and P.J. Gregory (eds.), *Soils in the Urban Environment.* Blackwell Scientific Publications, London. pp. 87-118.
12. Patterson, J. C. 1976. *Soil compaction and its effects upon urban vegetation.* In: *Better Trees for Metropolitan Landscapes Symposium Proceedings.* USDA For. Serv., Gen. Tech. Rept. NE-22. pp. 91-102.
13. Short, J. R. 1983. *Characterization and classification of highly man-influenced soils of the Mall in Washington, D.C.,* M. S. Thesis. Univ. Maryland.
14. Smith, H. 1976. *Soil survey of District of Columbia.* USDA-SCS.
15. Stipes, R. J. and R.J. Campana, (eds.) 1981. *Compendium of elm diseases.* APS Press, St. Paul, MN.
16. Taylor, J. H., A.C. Trouse, E.C.Burt, and A.C.Bailey. 1982. *Multipass behavior of a pneumatic tire in tilled soils.* ASAE Trans. 25:1229-1231, 1236.
17. Yelenosky, G. 1963. *Soil aeration and tree growth.* Int. Shade Tree Conf. Proc. 39:16-25.
18. Yelenosky, G. 1964. *Tolerance of trees to deficiencies of soil aeration.* Int. Shade Tree Conf. Proc. 40:127-147. ❑

G. B. Runion, H.H. Rogers, and S. A. Prior are with the USDA-Agricultural Research Service, National Soil Dynamics Laboratory, Auburn, AL 36831. C. W. Wood and R. J. Mitchell are with the Alabama Agricultural Experiment Station, Auburn University, AL 36849.

The authors appreciate the efforts of the National Park Service and the Smithsonian Institution personnel in providing technical assistance, reference materials, and the tree diameter data. We appreciate the technical support of Bernard McLean, John Walden, Hal McFarlin, and Larry McCoy.