Use of Pervious Pavements to Preserve Urban Forests and Urban Watersheds

Final Report

Dr. W. Todd Watson, PhD
Department of Ecosystem Science and Managment
Texas A&M University
and
Dr. Astrid Volder, PhD
Department of Horticultural Sciences

Introduction

Numerous research studies have demonstrated that mature urban trees provide many ecological benefits to urban areas. They reduce stormwater runoff, reduce air temperatures, and remove pollutants. Unfortunately, urbanization has resulted in the loss of large numbers of mature forest trees on the rural-urban fringe. Urbanization in the South continues to grow at a rapid pace with most states experiencing double-digit population growth over the last 10 years. This growth is having a negative impact on watersheds throughout the region. Much of this negative impact is due to the increase in impervious surfaces and the subsequent loss of mature tree canopy along the rural-urban interface. Impervious pavements poured around mature trees generally result in a rapid decline of tree health and premature tree death. Impervious surfaces such as parking lots, roads, and driveways, affect not only site hydrology; they also contribute to urban heat islands that exacerbate air quality problems.

Permeable pavements have a high infiltration rate, from 130 mm per hour to up to several thousand mm per hour (Bean *et al.*, 2007). This very high infiltration rate greatly reduces peak and total stormwater run-off rates, although the effectiveness strongly depends on the underlying soils. Porous concrete is most effective at reducing or completely eliminating run-off from small rainfall events. As the stormwater from a parking lot is filtered through the porous concrete and underlying soil, water quality can substantially improve (Ferguson, 2005), reducing the total phosphorus and nitrogen load by approximately 50% or more. Low available water, low oxygen, and high root zone temperatures under paved surfaces present a significant challenge to urban tree health and survival. Porous concrete will allow for easier infiltration of both water and oxygen to the root zone, which we expect to greatly benefit root growth and production. In addition, the higher water content of the soil will reduce the radiative impacts of the concrete on the soil temperatures.

Little is known about how trees will fare when grown in pervious pavement. The higher water availability, higher root zone oxygen, and lower root zone temperatures are expected to greatly improve the health and growth of the trees. Experiments were established to test the hypothesis that 1) soils under the pervious pavement will have higher summer soil moisture content than both the concrete and control treatment because

Figure 1. Trenching to establish 3m x 3m experimental plots.

of higher infiltration and lower evaporation rates, 2) trees in the pervious treatment would exhibit greater diameter growth than in the impervious treatment 3) trees in the pervious treatment will have reduced summer water stress, as evidenced by less negative water potentials, higher photosynthetic rates, and higher fluorescence ratios than those in the impervious treatment.

Materials and Methods

In Spring 2006, pervious pavement research plots were established at the Texas A&M University Research Farm near the Brazos River in Burleson County, Texas (30^{o}33'N, 96^{o}25'W). Test plots (3m x 3m) were trenched to a depth of 90 cm to remove roots that had grown outside of the pavement areas (Fig. 1). Root zones of twenty-five mature *Liquidambar styraciflua* (20 cm - 25 cm DBH sweetgums), were covered with four pavement combinations (dense concrete, pervious concrete, pervious concrete + water absorbing material (EcoDirt), and uncovered control). A water and root impermeable barrier (6 mil thick plastic sheeting) was installed at the edge of the concrete slabs and control plots to a 1 m depth to prevent root growth outside the experimental zone or lateral inflow of soil water into the experimental zone. This root barrier also simulated restricted root zones commonly found in most urban environments (Fig. 2). Concrete pads (9 cm thick) were poured on top of uncompacted soil without any base material between the soil and the concrete. Filter fabric was installed beneath the concrete pads to prevent plugging of the pore spaces in the concrete with soil particles (Fig. 3).

Figure 2. Plastic sheeting to contain roots within 3m x 3m experimental plots.

The soil was a heavy clay soil with a high plasticity index and a high shrink/swell potential. Shrinking and swelling from this type of soil is known to cause cracks in pavement, thereby reducing the useful life of the pavement. Trees exacerbate this problem by rapidly reducing soil moisture through transpiration. Typically, shrink/swell is reduced by compacting soil to minimize pore space, but compacted soil asphyxiates tree roots. To determine if soil shrinking and swelling could be reduced without compaction, EcoDirt, a burned silica material that absorbs water without swelling, was installed beneath five of the previous concrete plots and five of the control plots (Table 1). Holes (5 cm x 45 cm) were drilled vertically in the soil on a 30-cm grid pattern within the test plots and filled with EcoDirt.

Figure 3. Installation of pervious concrete around trees.

Soil moisture and temperature sensors (2 each/plot) were installed at two depths (5 cm and 35 cm) under each slab in November 2005. Six pvc pipes were installed vertically through each concrete pad and sealed to provide access ports to measure root growth and soil gases (Fig 4). Soil moisture and temperature data have been collected hourly since March 2007. Permanent dendrometers were installed on all tree trunks in March 2007 at 1.4 m to measure tree diameter growth, and data was collected bi-weekly. Leaf gas exchange rates, water potential, and fluorescence characteristics were measured in June and September of 2007, and light response curves of sun and shade leaves were collected in June 2007. Gas exchange and fluorescence characteristics were measured using a LI-COR 6400 with controlled temperature and light intensity. Pre-dawn water potentials were measured using a pressure chamber. In the fall of 2007, permanent soil collars were installed to measure soil CO2 fluxes as a proxy for root and soil microbial activity.

Table 1. Number of replicates per treatment

Pavement type:	Control		Pervious concrete		Impervious concrete
Ecodirt	yes	no	yes	no	no
# reps	5	5	5	5	5

Figure 4. Finishing concrete and installing access ports.

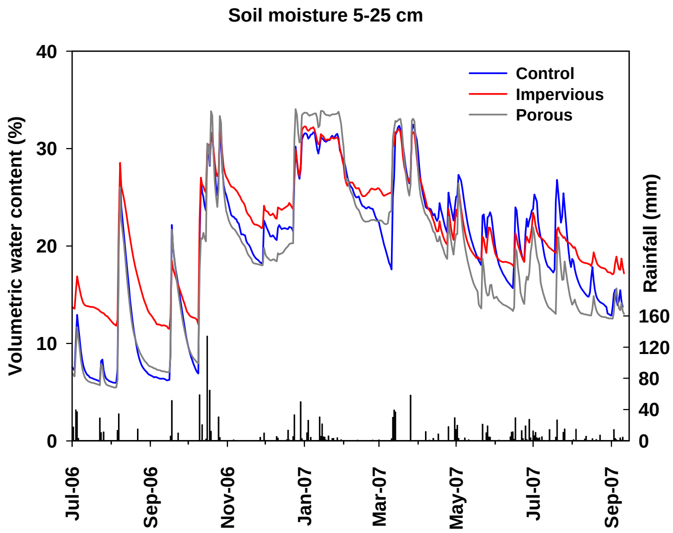

Figure 5. Soil moisture under the three pavement treatments. The two porous treatments were averaged for clarity. Rainfall events are indicated on the right axis.

Preliminary Results and Discussion

Trees in the porous treatments exhibited significantly higher diameter growth than the control and impermeable treatments during the spring of 2007; however, for the whole growing season diameter relative growth rate averaged 32 µm mm^{-1} day^{-1} for the control trees, and 31 µm mm^{-1} day^{-1} for the trees with the pervious pavement. The trees in the impervious treatment had a much reduced relative diameter growth rate of 23 µm mm^{-1} day^{-1}. One tree in each concrete treatment died of unknown causes, whereas one control tree died as a result of direct wind damage.

Preliminary soil water data suggest that soil water in the soil directly under the slab was higher under all three concrete treatments (Figure 5). Likely, the concrete slabs prevented evaporative soil moisture losses during the dry summer of 2006, while the open plots could not benefit from presumed superior water penetration into those plots due to a general lack of rainfall. As trees in the impervious plots had a lower growth rate than the trees in the control and pervious pavement, they likely would have had lower transpirative water losses as well, providing an alternative explanation for the higher soil water content in the impervious plots. Moisture levels deeper in the soil profile were consistently lower under impervious concrete, suggesting that compaction of the top layers under impervious concrete may impede infiltration into the deeper soil layers (Figure 6).

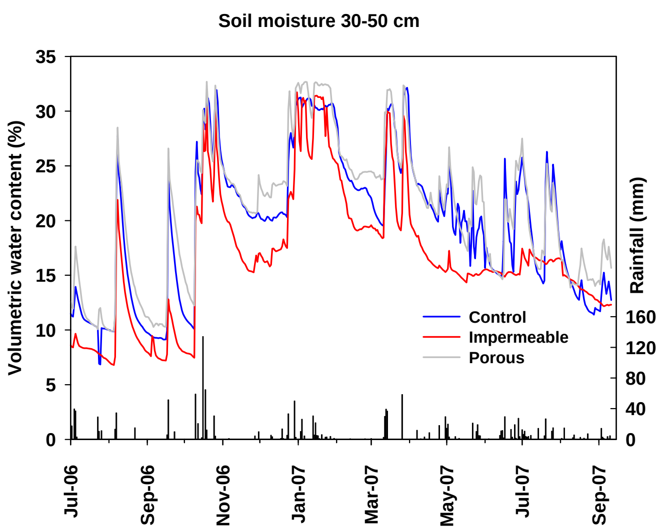

Figure 6. Soil moisture under the three pavement treatments in the deeper soil layer. The two porous treatments were averaged for clarity. Rainfall events are indicated on the right axis.

Due to excessive rainfall, the trees did not experience drought stress in 2007 (Figure 5 and 6), which limited the analysis of the physiological data. Light saturated photosynthetic rates were highest in the control plots and lowest in the impermeable plots (Figure 7), while fluorescence measurements indicated higher ‘stress’ levels (reduced photosynthetic efficiency) in the trees grown in the porous plots (Figure 8).

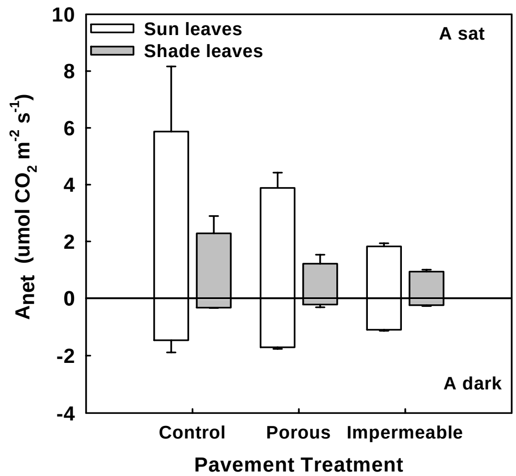

Figure 7. Light saturated gas exchange rates (A sat) and dark respiration rates (A dark) of sun and shade leaves in the three pavement treatments. Light response curves were fitted following Hanson *et al.* (1987).

The porous concrete does appear to provide a more beneficial environment to plant growth than impervious concrete. This likely is a function of increased water infiltration compared to the impervious concrete, as well as projected improved soil oxygen conditions. The beneficial effects of the pervious concrete are documented in both increases in diameter growth rate and higher photosynthetic rates compared to the impermeable concrete (Figure 7). Due to excessive summer rainfall in 2007, we have not yet been able to evaluate the effect of the two types of concrete or the EcoDirt under summer drought conditions. Further measurements will include continued monitoring of plant growth and physiology, as well as a detailed comparison of infiltration rates and water runoff quality. These data will be used to develop a model that will contrast the effects of various pavement options on down-stream water quality.

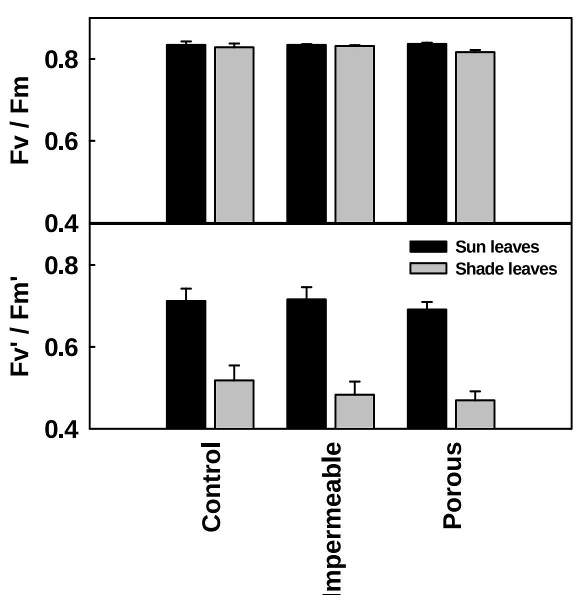

Figure 8. Fv/Fm (maximum light harvesting efficiency) and Fv’/Fm’ (actual light harvesting efficiency at PAR=1500 umoles m-2 s-1 (sun) and PAR=150 umoles m-2 s-1 (shade)) of sun and shade leaves of trees grown in the three pavement treatments.

Based on the preliminary data from this study, pervious concrete may be a viable option around existing mature trees in low traffic areas. In the short term, pervious pavement does not appear to be detrimental to trees compared to control plots and appears to be providing a better solution for the trees than impervious pavement. In addition, the impact of tree presence and the lack of soil compaction and fill show no obvious damage to either pervious or impervious pavement as a result of potential increases in soil shrinking and swelling potential.

Impact of Research

In 1987, Congress amended the Clean Water Act to establish the section 319 Nonpoint Source Management Program, which requires each state to develop a management program for controlling pollution added from nonpoint sources to the navigable waters within the state. Phase II stormwater programs to manage nonpoint source pollution are currently in effect. In addition, the 1990 Clean Air Act sets limits on how much of a pollutant can be in the air anywhere in the United States. States are required to develop state implementation plans (SIPs) to improve air quality. To meet these regulations two basic approaches can be used: 1) reduce the overall stormwater runoff from an area, and 2) reduce the level of pollution contained in runoff. Porous pavements can play a major role in these approaches by capturing the first flush of rainfall and allowing it to percolate into the ground.

Besides the expected benefits for stormwater management, pervious pavements can also be used for protecting indigenous mature trees in areas under development. Pervious pavements allow adjacent trees to receive more air and water. For large parking lots, this material has the potential to provide urban planners with an opportunity to minimize the negative impacts of impervious pavement on urban air and watersheds. More importantly, porous pavements make it possible to preserve mature trees during development because they provide parking spaces as well as a suitable root zones.

Additional funding is being sought to expand this important project. Future initiatives involve outfitting the research plots with minirhizotron tubes to document root growth dynamics. In addition, plans are underway to install guttering around the plots to document water movement through the site by logging runoff rates and water quality. Pervious concrete water infiltration rates and nutrient retention properties will be recorded to model water flow through sites with and without pervious concrete.

The following presentations have been given:

2006. Concrete Solutions for Trees: Structural Soils, Pervious Pavement and Aeration Systems to Improve Tree Health in Hostile Environments presented at the Bartlett Science Seminar in Austin, TX.

2007 Volder A, Watson WT. Soil moisture, gas exchange, and growth characteristics of mature sweetgum (*Liquidamber styraciflua*) trees as affected by different pavement options. In: Abstracts of the American Society for Horticultural Sciences (ASHS). 2007 Annual Meeting, Scottsdale AZ.

2007 Volder A, Watson WT. Soil moisture, gas exchange, and growth characteristics of mature sweetgum (*Liquidamber styraciflua*) trees as affected by different pavement options. 3rd Annual Central Texas Ecologist (CENTEX) Meeting. Temple, TX. 1 December 2007.

2007 Volder A, Watson WT. Soil moisture, gas exchange, and growth characteristics of mature sweetgum (*Liquidamber styraciflua*) trees as affected by different pavement options. 21st Annual Texas Tree Conference. Waco, TX. 10-12 October 2007.

Data printed in this report provides an overview of the Use of Pervious Pavements to Preserve Urban Forests and Urban Watersheds study. Data is still being analyzed and will be published in refereed journal articles.

Literature Cited

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