Urban Forestry & Urban Greening 12 (2013) 282–286

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Short communication

The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK

D. Armson[a,*], P. Stringer[b,1], A.R. Ennos[a,2]

[a] Faculty of Life Sciences, University of Manchester, Manchester M13 9PT, UK
[b] Red Rose Forest, 6 Kansas Avenue, Salford M50 2GL, UK

ARTICLE INFO

Keywords:
Amenity grass
Flooding
Interception
Runoff
Urban trees

ABSTRACT

It is well known that the process of urbanization alters the hydrological performance of an area, reducing the ability of urban areas to cope with heavy rainfall events. Previous investigations into the role that trees can play in reducing surface runoff have suggested they have low impact at a city wide scale, though these studies have often only considered the interception value of trees.

This study assessed the impact of trees upon urban surface water runoff by measuring the runoff from 9 m^2 plots covered by grass, asphalt, and asphalt with a tree planted in the centre. It was found that, while grass almost totally eliminated surface runoff, trees and their associated tree pits, reduced runoff from asphalt by as much as 62%. The reduction was more than interception alone could have produced, and relative to the canopy area was much more than estimated by many previous studies. This was probably because of infiltration into the tree pit, which would considerably increase the value of urban trees in reducing surface water runoff.

Introduction

The process of urbanization greatly alters the hydrology of an area, reducing the amount of infiltration into the soil and increasing the speed at which water travels over the surface, thus significantly increasing both surface water runoff and peak discharge rates (Leopold, 1968; Douglas, 1983; Sanders, 1986; Asadian and Weiler, 2009). The remedy applied by engineers has typically been to increase the number of sewers and drainage channels (Douglas, 1983; Sanders, 1986), which is both costly and disruptive to other underground services. Increasingly, sustainable drainage systems (SuDS) are being used to increase the level of drainage for an urban area, while minimizing the pollution risk from these water drainage systems (Ellis et al., 2002; Abbott and Comino-Mateos, 2003; O'Sullivan et al., 2011). SuDS utilize various methods to control water pollution and movement, but primarily these systems are based around the use of permeable hard surfaces and the increased use of vegetation to reduce runoff. The use of urban greenspace, in particular urban forests, is therefore increasingly being identified as a tool to reduce runoff and so mitigate the negative effects of urbanization upon the hydrology of urban areas (Bartens et al., 2008).

The effect of trees upon surface water runoff has been extensively studied in both forests and agricultural areas. For instance Ellis et al. (2006) demonstrated that tree belts can reduce runoff from an agricultural grassed slope by 32–68% in a one in ten year storm event (24.5 mm in 30 min) and by 100% in a one in two year storm (48 mm/h for 13 min) event. Joffre and Rambal (1993) showed that trees planted on grassland slopes increased water storage beneath their canopy, again reducing erosion and surface water runoff. These studies highlighted the important role that tree roots perform in increasing infiltration in the root and surface soil zones in agricultural areas, so reducing surface runoff.

Studies conducted in larger areas of forest showed the same benefits of runoff reduction through infiltration. The catchment-wide modelling approach used by the US Soil Conservation Service (NRCS, 2004) and by Whitford et al. (2001), showed a runoff coefficient of only 0.20 for a 12 mm rainfall event on a moderately to well drained forest. This demonstrates how little runoff from can occur from forests under heavy rainfall. Simulations by Brooks et al. (1994), investigating the consequence of tree removal in forested areas, found that deforestation would greatly alter the response of areas to rainfall. Slopes that were forested would delay the response to rainfall by as much as 11 min and reduce the discharge rate to only 16% of the rainfall rate (Brooks et al., 1994). Slopes that had recently been forested would respond in seconds and only reduce discharge rates to 92% that of rainfall, reaching peak discharge rates within 3 min (Brooks et al., 1994).

* Corresponding author. Tel.: +44 161 275 3848; fax: +44 161 275 3938.
E-mail addresses: davearmson@gmail.com (D. Armson), pete@redroseforest.co.uk (P. Stringer), r.ennos@manchester.ac.uk (A.R. Ennos).
[1] Tel.: +44 161 872 1660; fax: +44 161 872 1680.
[2] Tel.: +44 161 275 3848; fax: +44 161 275 3938.

1618-8667/$ – see front matter
http://dx.doi.org/10.1016/j.ufug.2013.04.001

As well as increasing infiltration rates, trees also reduce overland flow by intercepting rainfall. Tree canopies intercept and store water on their leaves and stems during rainfall events and this water is subsequently evaporated. In forested areas, interception loss can be as much as 20–75% of the total evapotranspirational loss (Gash and Stewart, 1977; McNaughton and Jarvis, 1983; Shuttleworth, 1988). However, the gross interception rate varies greatly with species, tree size, planting density and previous canopy wetness, resulting in a large spread of gross interception values.

These studies highlight the value of trees in reducing surface water runoff in rural areas. Transfer of this knowledge to the urban environment, however, where runoff is becoming an increasingly important issue, can be difficult as the conditions differ dramatically. Most obviously, the benefit of the increased infiltration in woodland will be greatly reduced in cities because the roads and pavements, above which many urban trees grow, have sealed surfaces which increase the overall surface runoff (Douglas, 1983; Pauleit and Duhme, 2000). Surfaces such as asphalt respond quickly to rainfall and can shed 90% of received rainfall to drain (Pauleit and Duhme, 2000), pushing the limits of drainage systems in heavy rainfall events. This heightens the importance of greenspaces, such as parks, in which trees grow above swards of grass, where runoff coefficients as low as 26% have been recorded (Sanders, 1986). As the benefit of increased infiltration provided by trees can be reduced by surface sealing, an increased emphasis has been placed upon the benefit of rainfall interception by tree canopies. Many studies have shown that significant amounts of rainwater can be held and evaporated from tree canopies, reducing and delaying the response of an area to rainfall events. Guevara-Escobar et al. (2007) and Asadian and Weiler (2009) investigated the canopies of *Ficus benjamina* and *Thuja plicata* respectively and found that single tree canopies could intercept around 60% of rainfall on average. These figures are much higher than those found by Xiao et al. (2000) and David et al. (2006), who looked at *Pyrus calleryana* and *Quercus ilex* respectively, placing interception loss from individual trees at 15% and 21.7%, though these trees were under ten years old. Interception by even smaller trees can be even lower; Aston (1979) found that the canopy of six different eucalypt species of height 1.3–1.7 m retained only 1 kg of water before saturation was reached, a water depth of only 0.1 mm. All these studies agree, however, that interception loss can alter dramatically between rainfall events; greater rainfall intensity and longer rainfall durations both reduce the effectiveness of rainfall interception (Xiao et al., 2000; David et al., 2006; Guevara-Escobar et al., 2007; Asadian and Weiler, 2009).

Though the results of total interception loss are variable between species, size and general climate conditions, these studies have allowed the construction of computer models to assess the impact of tree cover over large urbanized areas. By separating urbanized areas into various land use types, computer models can be used to assess the response of small areas of particular land use types to varying rainfall events. Combining these smaller areas, a picture of a whole city's response to rainfall events can then be calculated. Using these techniques, various studies have assessed the impact on runoff of increased or decreased tree cover in urban areas. Sanders (1986) modelled the removal of 22% tree cover from Dayton, Ohio, which resulted in an increase in runoff of 7%; conversely, increasing tree cover by 27% only decreased runoff by 4%. These results are in close agreement with those of Lormand (1988; cited by Xiao et al., 1998) who found that an increase of 25% tree cover only reduced runoff by 4% for a small arid watershed in Arizona. Gill et al. (2007), modelling the potential runoff reduction produced by trees in Manchester, UK, found that in a 28 mm event, an increase of 10% tree cover in high density residential areas could reduce surface runoff by 5.7%. Though the results from these studies seem to indicate that tree cover has only a small effect upon surface runoff, most models primarily use the results of interception studies to generate the final runoff reduction values. This method does not take into account the impact that the open tree pits may be having upon urban infiltration. While infiltration will undoubtedly play less of a role than in rural areas, much surface water may still flow into the permeable area around the tree base rather than the drains. Tree pits may therefore further reduce surface water runoff, draining water which fell outside the tree canopy as well as through it. Thus any study comparing the effectiveness of trees and grass in reducing runoff should measure the actual amount of water that runs off into drains, rather than that which strikes the ground beneath the canopy. In this study, therefore, we constructed plots with three typical urban surfaces: an area of asphalt, an area of asphalt with a tree planted centrally; and an area of turf grass, and examined the runoff of rainfall from them into drains situated at their corners. This should better reflect the impact that surface type and standard tree plantings can have upon the watershed of urban areas.

Materials and methods

Test plot locations and construction requirements

Investigations about how surface type and tree cover affects surface water runoff in urban areas were conducted at five sites in Manchester, UK, from January to September 2011. The sites were located 1–2 km South of Manchester City Centre along the Oxford Road corridor. In total, nine experimental plots were set up, four at Whitworth Park two at Manchester Science Park with the remaining three constructed at The Academy High School, the University of Manchester Dilworth Street car park and All Saints Park. Open sites, large enough to allow easy construction of the experimental plots (completed in October and November 2009) were chosen, so that rainfall would not be obstructed by existing tree cover. Supply issues delayed tree planting until September 2010 and the study continued until autumn 2011, when leaf fall caused drainage problems, requiring the project to be ended.

Experimental plot design

The experimental plots at each site were identical in construction and were composed of three individual 3 m × 3 m plots. One plot's area was surfaced with asphalt, one with grass, and one with asphalt with a 1 m × 1 m tree pit in the centre, planted with a field maple (*Acer campestre*). The asphalt plots were surfaced with cold set asphalt and sealed with Star Uretech EC 1000 sealant to replicate surfaces such as roads, pavements and building which all have extremely low infiltration rates. The grass plots were turfed with an amenity grassland mix and mown regularly to replicate the parks and gardens found in urban centres. Asphalt in the tree plots were sealed in the same way as the asphalt plots, and the surface of the soil within the open tree pit was 30 mm lower than the asphalt surface and topped with a woodchip layer, to bring it level with the asphalt. The trees were planted in existing site soils, which varied from soil containing a high proportion of building rubble (the Academy and Dilworth Street) to loams with a high organic matter content (Whitworth and All Saints parks, and Manchester Science Park). *Acer campestre* was selected as this species is commonly used in urban plantings and all trees used for this study were of similar age (7–9 years); with mean and standard deviation of crown area $3.27 \pm 0.66\ m^2$ (corresponding to just over a third of the plot area), height 4.89 ± 0.10 m, and LAI 1.13 ± 0.16 (very low for a street tree). This planting method replicated that commonly used in pavement plantings across suburban areas of Manchester. The individual surfaces were constructed adjacent to each other, and each surface was