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# Mitigation of winter rainfall by hedges – does plant choice matter?

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**Abstract**: Local flooding events are common in urban environments where impermeable surfaces are becoming a dominant component of the landscape. Nature-based and space-saving solutions, such as hedge planting, create strips of permeable surface where excess water can percolate and reduce pressure on sewer systems. Previous summertime experiments found that the rate of plant evapo-transpiration (ET) is directly linked to replenishing the soil's capacity to hold water, suggesting that plants with high ET rates would be beneficial in certain contexts to mitigate excess rainfall. This study investigates the rarely-studied winter ET rates/water use of five evergreen hedge species and cultivars. Three year old hedging plants were grown individually in 7.5 l pots in an outdoor field experiment (February-April 2021) in SE England. ET rates were measured at various intervals during this period and weather data collected from an adjacent weather station. We found significant species and cultivar differences in ET, with *Thuja plicata* '4ever Goldy' consistently transpiring most on a per plant basis (on average over 150 mL/day even in average daily temperatures <5°C) and showing least variation in water loss in relation to solar radiation, but most in response to temperature. *Thuja plicata* 'Atrovirens' transpired most per unit leaf area (0.93 mL $cm^{-2}$) and varied least in response to air temperature, but most in response to solar radiation. This suggests some scope for considering different types of planting to mitigate winter rainfall depending on the space available and prevailing environmental conditions. We are continuing with year-round monitoring with the view of linking particular plant functional and structural traits (canopy density/volume, branch angle, root system size) to the delivery of this ecosystem service.

**Key words**: evapo-transpiration, garden hedges, green infrastructure, hedge cultivars, urban hedges

## INTRODUCTION

Presence of impervious surfaces in the urban environment is linked to increased flooding risks (Warhurst et al. 2014). Nature-based and space-saving solutions, such as hedge planting, create strips of permeable surface where excess water can percolate and reduce pressure on sewer systems; this could help mitigate some of the urban flood risks. Previous experiments found that the rate of plant evapo-transpiration (ET) is directly linked to replenishing the soil's capacity to hold water, suggesting that plants with high ET rates would be beneficial in certain contexts to mitigate excess rainfall (Blanusa and Hadley, 2019). However, these experiments only characterized plants' summertime function, when most deciduous plants are at peak photosynthetic and ET capacity. The notion that evergreen planting can provide greater year-round benefit due to the presence of foliage had been noted previously (e.g. Blanusa et al. 2015).

This however requires testing in various seasons and understanding to what extent lower winter temperatures, solar radiation and light intensity reduce ET and thus limit plants' capacity for alleviation of winter flooding risks. Previous studies have found close correlations between transpiration and solar radiation (e.g. Mapeto et al. 2018).

The aim of our experiment was to investigate winter-time water use of several plant species that can be used as hedgerows. It is a start of a broader project which looks into the importance of cultivar-level differences in the provision of ecosystem services (flood mitigation, cooling and air quality improvement), using a range of plant species (deciduous and evergreen) and associated cultivars and study them in all seasons of a year under a range of environmental conditions. Outcomes of this should be useful to inform planting decisions in various green infrastructure and microclimates, to maximise the level of ecosystem services' delivery.

## MATERIAL AND METHODS

### Plant choice and arrangement

A selection of five evergreen taxa was made based on their availability in the horticultural trade and their frequency of use in the everyday garden setting. We selected plants from a range of functional types, i.e. conifers vs. flowering plants and native vs. non-native, while also incorporating different canopy structures (more or less upright or spreading, greater or smaller leaf area).

Three year old hedging plants with dimensions specified to a height of 60 cm were used, in order to facilitate comparison between plants of similar size, as would be the case in a formal hedge in a garden or urban setting. These were grown individually in 7.5 L pots in Sylvamix (Melcourt, UK) potting compost. The experiment was set up within an outdoor polytunnel with open sides at the Field Research Facility of the Royal Horticultural Society (RHS) in Wisley, SE England. Ten replicates of each of the five chosen taxa were used (see Table 1 and Figure 1 for detail). Plants were positioned 50 cm from each other in a randomised order in a single block.

*Table 1 Plant material used in the experiment*

| **Plant taxon** | **Native/Non-native** | **Gymnosperm/Angiosperm** | **Canopy and leaf characteristics** |
|---|---|---|---|
| *Juniperus communis* 'Arnold' | Native | Gymnosperm | Columnar canopy, small juvenile needles |
| *Elaeagnus x submacrophylla* 'Gilt Edge' | Non-native | Angiosperm | Broad canopy, waxy broad leaves, with peltate scales beneath |
| *Thuja plicata* 'Atrovirens' | Non-native | Gymnosperm | Excurrent canopy, leaf scales adpressed |
| *Thuja plicata* '4ever Goldy' | Non-native | Gymnosperm | Excurrent dense canopy, leaf scales adpressed |
| *Thuja plicata* 'Whipcord' | Non-native | Gymnosperm | Weeping canopy, branches cylindrical with adpressed leaf scales |

*Figure 1: Experimental set-up of the selected taxa*

### ET assessment

Plants' ET was assessed by measuring potted plant weight change during 7 day-intervals, repeated four times (February-April 2021) using a precision balance (CBK 32, Adam Equipment, Milton Keynes, Buckinghamshire, UK). On Day 0 of each 7-day interval, plants were watered until fully saturated, left to drain for 1 h and then weighed to record the starting point. On day 7 plants were re-weighed and the difference in weight was recorded as evapo-transpirational plant water loss. The assumption was that there was equivalent evaporation of water from the growing media surface for all samples.

### Determination of leaf area

To allow comparison of water uptake on a per leaf surface area basis, we calculated the total leaf surface for each plant using direct and indirect approaches. For *Elaeagnus* we used herbarium specimens from the Wisley collections to measure 17 randomly chosen leaves using the image processing software ImageJ (Schneider et al. 2012) and averaged their leaf surface. Following that, we randomly selected three plants and counted all the leaves manually, and multiplied it by the average leaf surface to calculate average canopy leaf area for this species.

For *Thuja* and *Juniperus*, the leaves are modified into scales and needles respectively. These structures form a highly complex 3-dimensional photosynthetic apparatus that is difficult to scan, and almost impossible to divide and manually count. For *Juniperus* we destructively harvested one plant at the end of the experiment and measured the number of stems, their diameter and circumference, their height and their weight. Each stem was then stripped of all the photosynthetic material, leaving only bare wood, which was weighed again, giving us a ratio of the weight of photosynthetic material per stem. We then scanned individual branches and weighed them to obtain a ratio of weight to surface area. Because needles are photosynthetic on both surfaces, we multiplied the surface area by two. Linear regression was used to produce an allometric formula, based on five stem measurements, using 'stem height * stem diameter' as the independent variable and 'stem weight' as the dependant variable. Finally, we counted and measured the stems for five plants chosen at random and applied our formula to estimate their total leaf surface area.

For our three varieties of *Thuja*, we cut segments of foliage and scanned them using the program WinDIAS Leaf Image Analysis System (Delta-T Devices, Cambridge, UK) before applying a standardized count method, whereby we simply measured the dimension of the stems that had been cut, and counted how many equivalents were on each plant. For *Thuja plicata* 'Atrovirens' and '4ever Goldy', the foliage also photosynthesizes on both surfaces, so we multiplied the total surface by two. For *Thuja plicata* 'Whipcord', the photosynthetic stems are cylindrical, so we multiplied the surface by a value of π (3.14).

### Statistical analyses

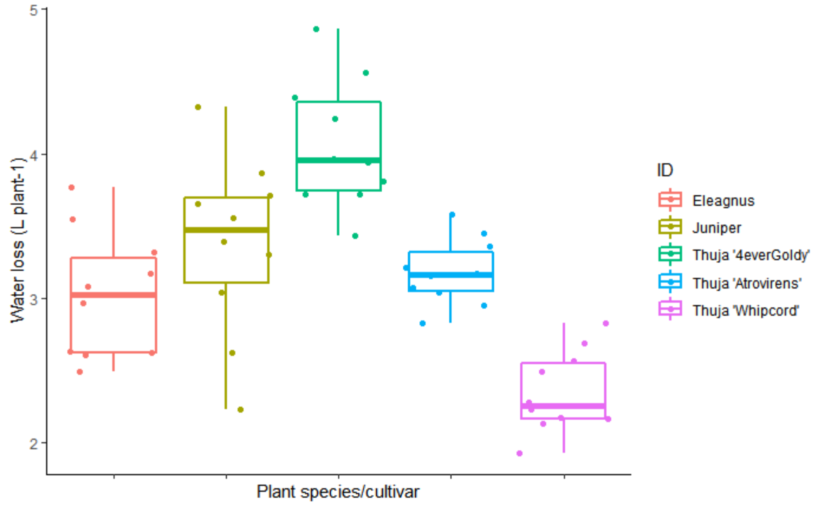
All statistical analyses were made using the R programming language v.4.0.4 (R Core Team, 2021) made available in RStudio v. 1.4.1717 (RStudio Team, 2020).

Micro-climatic variables were extracted from the weather station adjacent to the experimental site. For each interval of measures, we calculated the average temperature, average Relative Humidity (RH) and total amount of solar radiation for the studied periods. We also calculated the relative amount of solar radiation per day by dividing total solar radiation by the number of days in each interval.

For each taxon, we plotted their ET per week and modelled this relation with temperature, light intensity and relative humidity (RH) using robust linear regression (function "rlm" in the package "MASS" v. 7.3-55).

## RESULTS

*Thuja plicata* '4ever' had highest total ET, with an average total of 4.1 L (SD ±0.44) over the experimental period, and *Thuja plicata* 'Whipcord' lowest, with an average of 2.3 L (SD ±0.28). When comparing ET per unit leaf area, *Thuja* 'Atrovirens' was highest with 0.9 mL/cm$^2$ (SD ±0.08) and *Juniperus communis* 'Arnold' lowest (0.6 mL/cm$^2$ (SD ±0.13) (Figure 2).

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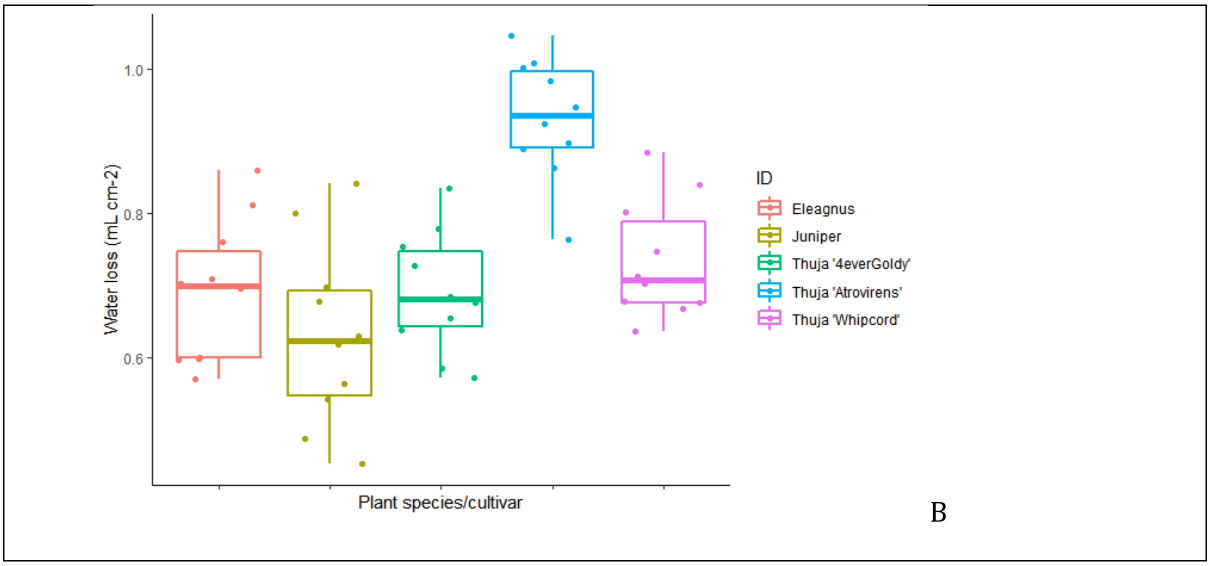


*Figure 2: Water loss (ET) over the experimental period expressed on A) whole plant basis, and B) ET per unit leaf area.*

Evapo-transpiration rates varied in the four studied weeks, with the third measurement interval showing a drop in ET which appeared predominantly linked to a drop in air temperature (data not shown). In terms of environmental drivers of ET, increase in air temperature appeared key in *Thuja* '4ever Goldy' ($R^2 = 0.57$) and least in *Thuja* 'Atrovirens ($R^2 = 0.08$), while an increase in solar radiation seemed to have most impact on *Thuja* 'Atrovirens ($R^2 = 0.35$) and least in *Thuja* '4ever Goldy' ($R^2 = 0.04$) (Figure 3).

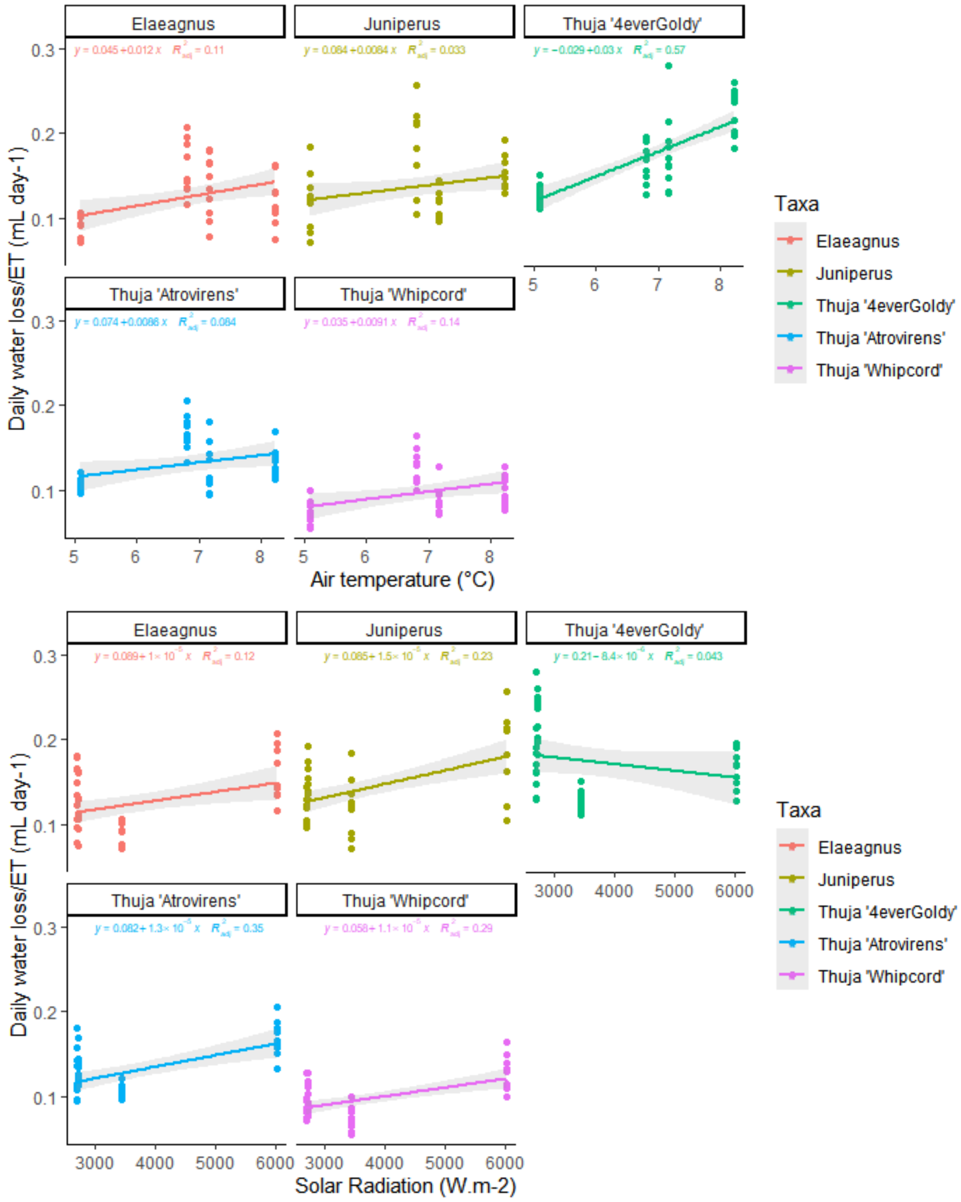


*Figure 3: Scatterplots showing linear relationship between ET vs. air temperature (top panel) and ET vs solar radiation (bottom panel)*

## CONCLUSIONS AND FUTURE WORK

While it is not surprising that different plant taxa (species and cultivars) vary in their evapo-transpiration rates, both in terms of absolute rates, on a per 'whole plant basis' and in relative terms, per $cm^2$ of leaf area, we are exploring the practical implications of this. We are studying if for example smaller, more 'efficient' plants could be used in smaller spaces to provide benefits on par to those of larger plants. This was a preliminary study based on one season (winter) which highlighted the complexity of the interaction between the plant taxa and some environmental drivers of the evapo-transpiration. The differences between cultivars within a species, something rarely focused-on in literature, rather than only between plant species, were particularly stark. Cultivar choice is mainly considered for its visual appeal but here we begin to show (based on an example of several *Thuja plicata* cultivars: 'Atrovirens' '4ever Goldy' and 'Whipcord') that not all cultivars within a species act the same. Using ET as a model parameter and a proxy for rainfall mitigation by plants, we established inherent cultivar differences in this parameter (driven by differences in leaf area and plant size), and differences in which environmental drivers increased this parameter most. This could have implications in terms of placing the most appropriate cultivars into different garden and green infrastructure situations, seeking to account for varying microclimates.

We are now continuing our work on this in various seasons and focusing on a wider range of species and cultivars to establish underlying plant traits required for the year-round provision of rainfall mitigation services.

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