

Stormwater infiltration trenches with engineered drainage balance runoff retention and healthy tree growth

Les tranchées d'infiltration des eaux pluviales avec un drainage technique équilibrent de concilier la rétention des eaux de ruissellement et de croissance saine des arbres

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RÉSUMÉ

La plantation d'arbres à côté d'ouvrages d'infiltration pour la gestion des eaux pluviales peut augmenter la rétention de ruissellement et supporter la croissance et la santé des arbres. Cependant, ces deux performances nécessitent un équilibre entre le volume d'eau stocké dans le substrat de l'ouvrage et le risque de créer un sol saturé d'eau et donc des conditions anoxiques pendant de longues périodes. Les sols de structure (du gravier enrobé d'argile limoneuse) peuvent fournir un volume important pour le stockage d'eau infiltrée ainsi pour le développement de racines des arbres avoisinantes, mais avec la possibilité de maintenir une chaussée imperméable. Dans les sols à forte teneur en argile lourde, la réponse de la croissance d'un arbre à l'implantation de l'ouvrage d'infiltration pourrait être grâce à l'irrigation passive ou l'amélioration de la structure du sol (ou bien les deux). La présente étude a donc suivi la dynamique du niveau d'eau et la croissance d'arbres avoisinantes, pour des tranchées d'infiltration remplies du sol de structure et recevant le ruissellement d'un parking, dans la banlieue de Pakenham, en Australie. Parmi les 6 tranchées (Long.=12m, Larg.=0.6m, Prof.=0.6m), 3 avaient un exutoire élevé (350 mm au-dessus du fond de la tranchée) et 3 ne recevaient pas du ruissellement et ne possédaient donc pas d'exutoire (s'agissant comme contrôle). La rétention du ruissellement dépendait fortement du taux d'exfiltration autour de la tranchée et les tranchées avaient un niveau d'eau plus élevé que prévu. Le taux de croissance, la densité du couvert et la santé des feuilles des arbres étaient plus importants pour les tranchées alimentées en eaux pluviales (par rapport aux « contrôles »). Les résultats mettent en évidence la capacité de tranchées d'infiltration de sol de structure de réduire le volume de ruissellement et éviter la stagnation d'eau, à condition que les tranchées soient d'un volume suffisant, possèdent un exutoire élevé du fond de la tranchée et permettent l'exfiltration des eaux pluviales.

ABSTRACT

Trees can be planted adjacent to stormwater infiltration systems to improve runoff retention and tree health and growth. Both runoff retention and healthy tree growth depend on the balance between designing a large volume of water storage in the infiltration systems adjacent to trees, while not creating anoxic, saturated soil water conditions for extended periods. Structural soil (hard stone aggregates coated in clay loam soil) can provide large storage volumes, space for root growth and water uptake from adjacent trees, and flexibility to pave on top. In heavy clay soils, it is possible that any improvement in tree growth in response to adjacent infiltration trenches is due to a) passive irrigation of runoff water or b) improving soil structure. We measured water level dynamics in six structural soil infiltration trenches and tree growth rates planted next to those six trenches, next to a car park in Pakenham, Australia. Three structural soil trenches (L=12m, W=0.6m, D=0.6m) with raised (350 mm) drainage outlets creating water storage received runoff from 80 m² catchments (the impervious carpark) and three structural soil trenches (L=6m, W=0.6m, D=0.6m) did not receive car park runoff nor were fitted with drainage. Runoff retention was primarily affected by exfiltration rate and structural soil trenches filled more than anticipated. Growth rates and canopy density were higher for trees receiving runoff from the carpark, and they also had better leaf health. Our results show large volume trenches with drainage and internal storage are effective at reducing runoff and preventing waterlogging for trees in poorly draining soils.

KEYWORDS

Stormwater infiltration, street trees, runoff retention, structural soil, waterlogging

1. INTRODUCTION

Trees improve the liveability of cities by providing shade, evaporative cooling and stormwater mitigation, which benefits human health and wellbeing and can reduce energy demand (Livesley et al., 2016). The ecosystem services trees provide increase with size and age, yet urban trees have high juvenile mortality rates and shorter lifespans (Hilbert et al., 2019). Passively irrigating trees by planting them in or next to stormwater infiltration systems can increase juvenile tree growth (Grey et al., 2018), along with improving runoff retention (Berland et al., 2017). The faster trees increase their size, the higher their chances of survival are and the greater runoff reduction they provide.

Both runoff retention and healthy tree growth depend on the balance between designing a large volume of water storage in the infiltration trenches and not creating anoxic, saturated soil water conditions for extended periods. Where inlets can maintain high flow capacity, runoff capture is limited by the exfiltration rate of surrounding soils (Winston et al., 2016). In heavy clay soils, typical to developing outer suburban areas of Melbourne, hydraulic conductivity is very low (<1mm/hr). Thus, key to exfiltration is to have large storage volumes and surface areas so sufficient amounts of runoff exfiltrate before the next rainfall event. Long, continuous sub-surface infiltration trenches filled with gravel can provide large storage volumes and surface areas. However, they need to share space with underground services, pavements, driveways and there needs to be soil space for tree roots to colonise. Structural soil can be used to fill the trenches, as it is matrix of stone and soil that can be compacted to support paving, roads and topsoil, yet has large pores that encourage root growth, allow fast infiltration and water storage (Grabosky and Bassuk, 1995). Replacing compacted heavy clay soil with fast draining, well-structured structural soil should also improve tree health and growth (Moore et al., 2019).

We quantified stormwater retention performance and tree growth improvement from a long structural soil trench design. As increases in tree growth can be attributed to increased water supply or substrate change, we installed structural soil trenches with and without connections to stormwater runoff. We aimed to (i) quantify runoff reduction volumes and identify key drivers of retention, (ii) determine whether tree growth was increased and if the improvement can be attributed to increased water and substrate change or substrate change alone.

2. METHODS

2.1. Study site and experimental design

The experiment was located at a compacted site with heavy clay soil, next to a car park in Pakenham, an outer suburb 53 km from the Melbourne CBD, Australia. 12 juvenile *Eucalyptus leucoxylon* trees were planted (i) next to a trench of structural soil with stormwater inflow, (ii) next to the structural soil trench only, or (iii) planted into the native soil (Fig 1). Tree growth and stormwater retention was monitored for 18 months. The climate at the site is temperate with a mean annual rainfall of 804 mm year⁻¹ (1990-2022) and a mean maximum temperature of 19.9 °C (1990-2022). Rainfall is relatively evenly distributed throughout the year and there are on average 110.2 days with rain over 1 mm (BoM, 2022)

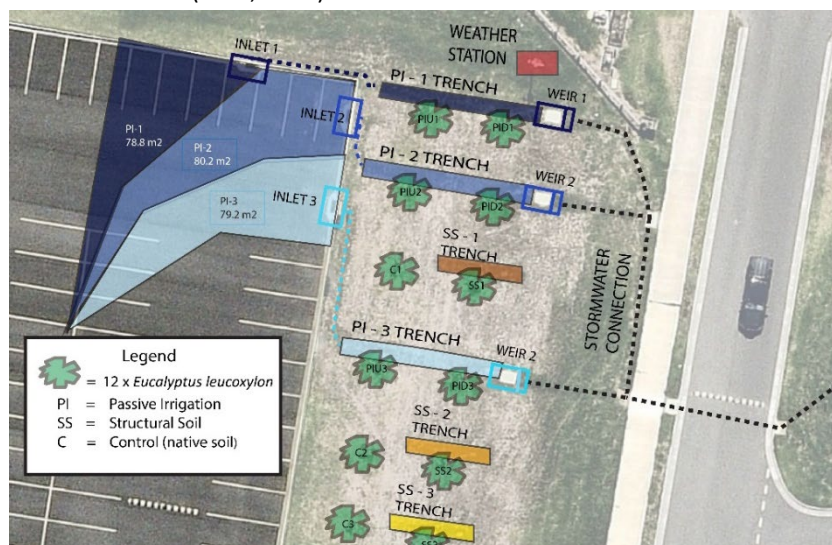


Figure 1. Diagram of the experimental site.

2.2. System design

Passively irrigated trees (PI) had two trees planted evenly spaced next to a structural soil trench (12 m long, 0.6 m wide and 0.6 m deep). A corner section of the carpark was evenly divided into three catchments which created runoff that drained into kerbs via grated side entry inlets. The inlets fed into 225 mm capped slotted PVC pipes at the bottom of the trenches and the end of the pipes were in concrete junction pits. Overflow outlets created 350-400 mm of storage along the trench and V notch slotted weirs were installed to monitor overflow volumes. The treatments were divided into upslope (PIU) and downslope (PID). Three structural soil trenches (6 m long, 0.6 m wide and 0.6 m deep) not connected to impervious surfaces or drainage had one tree each planted adjacent to them and the trenches were also at the bottoms of the slopes. Control trees were planted into the native soil with no amendments.

2.3. Runoff generation and retention

A rain gauge was installed and rainfall was aggregated into events using a six-hour inter-event minimum. To determine runoff generated, we calculated volume (m^3) and depth (mm) using catchment area (m^2), which were 78.2 m^2 , 80.2 m^2 and 79.2 m^2 . Water level in all trenches were continuously monitored on a one-minute time-step by pressure sensors installed in a slotted PVC pipe stilling well, 1 m downslope from PID and SS trees. To quantify runoff reduction all positive changes in water level during a rainfall event were added, converted to volume by multiplying by infiltration trench area (7.2 m^2) and by 0.4 to account for porosity of structural soil.

2.4. Tree growth

Stem diameter was measured every 4 weeks 30 cm above the soil surface. The first measurements were taken on 24 August 2021 and the final measurements were taken on 4 November 2022. As trees differed in size at the start of the experiment, growth response was calculated as a percentage of starting size.

3. RESULTS AND DISCUSSION

Tree growth was higher for trees in passively irrigated and drained treatments compared to the undrained structural soil, however differences were not significant ($p=0.057$) (Fig 2). Slower growth and leaf stress was likely due to the structural soil trenches filling with water and having nowhere to drain, raising the water table and

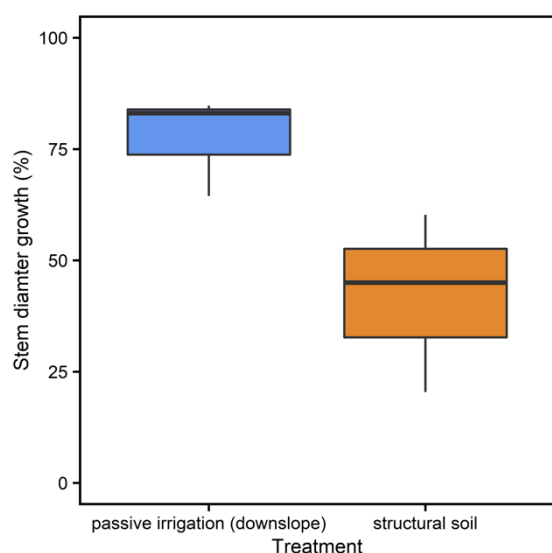


Figure 2. Stem diameter growth (%) over 14 months between passively irrigated and structural soil only treatments ($n=3$).

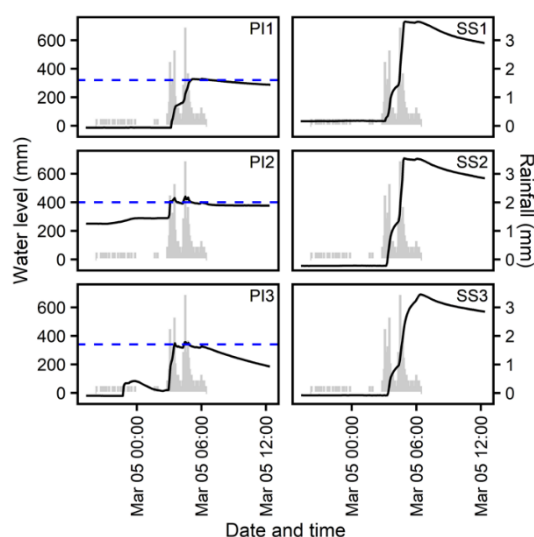


Figure 3. An event of 9.6 mm in March 2022. Water level of each trench is shown as a line on the left y-axis and rainfall (mm) are bars on the right y-axis. The blue line is the overflow level in drained passively irrigated treatments.

saturation of the soil. Our results are consistent Grey et al. (2018) where trees planted directly in an infiltration system on heavy clay soil had slower growth compared with trees with drainage. In their study several replicates died of waterlogging, while in our study trees were still alive and growing. This could be due to our trees being planted next to and not in the trench. Although no death occurred, trees in the structural soil treatments appeared stressed, particularly during the wet spring months, with sparse canopies and spotty leaves suggesting

nutrient deficiency and showing higher intensities of insect damage (Figure 4). Anoxic soil conditions due to waterlogging limit water and nutrient uptake by tree roots and can result in reduced photosynthetic functioning (Kreuzwieser and Rennenberg, 2014). While pest insects have been shown to increase on Eucalyptus trees that experienced waterlogging (Stone et al., 2010). It is unclear whether the undrained trenches exacerbated waterlogging or not, as control trees were planted upslope, experiencing drier conditions. However, if using structural soil trenches in low lying areas we recommend installing drainage to avoid any waterlogging effects.

As the results are preliminary, total runoff reduction for the whole experimental period has yet to be quantified and validated. However, it is clear variations in exfiltration determine runoff retention potential. Fig 3. illustrates the differences in trench filling and exfiltration between replicates in each treatment. After a period with low rainfall and higher evaporative demand at the end of summer all trenches except PI2 were empty. Around 9 mm of rain fall within 4:00 and 6:00 and all the trenches filled rapidly. Because the passively irrigated treatments had overflows installed the level of the trenches did not exceed 400 mm, while structural soil trenches reached 700 mm, which was almost at the soil surface, raising water levels closer to tree roots. Consequently, in spring 2022, the mean water level for passively irrigated trenches was 193 mm and 454 mm for structural soil trenches.

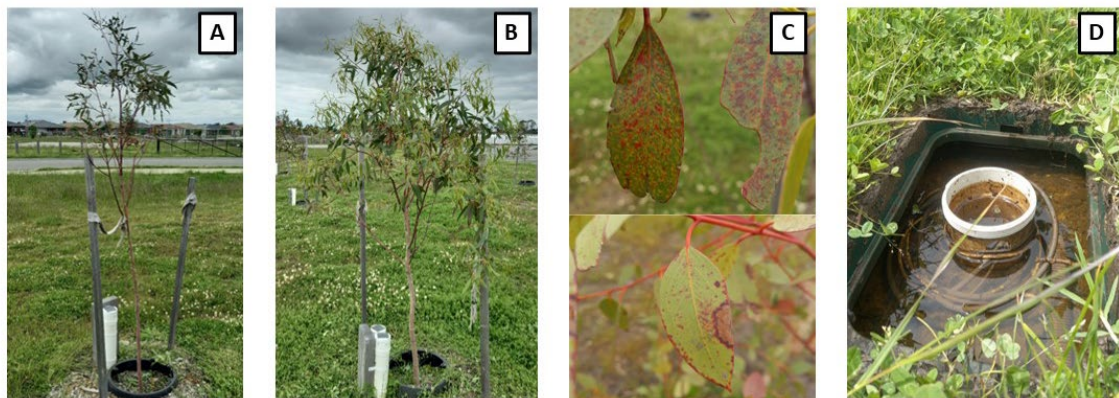


Figure 4. A) Tree in structural soil only treatment with poor growth. B) Passively irrigated tree with robust growth. C) Signs of nutrient deficiency and pest attack from anoxic soil conditions in tree in structural soil only treatment. D) Structural soil trench without drainage severely waterlogged. All photos were taken in November 2022.

4. CONCLUSION

Our preliminary results indicate exfiltration rate is the limiting factor for runoff retention, while drainage is critical for tree health. At the time of writing this abstract, trees receiving stormwater runoff into storage and drainage have higher growth rates, although not yet significantly different. Measurements will continue for a further 3 months until the end of summer.

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