New Zealand plant growth trials in rapid biofiltration media

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Summary

Media used in rapid bio-filtration devices have hydraulic conductivity rates exceeding 2500 mm/hr. Stormwater360 New Zealand has partnered with Contech USA to produce a rapid filtration media using locally available materials. Current bio-retention guidance limits the hydraulic conductivity of media to less than 350 mm/hr to support plant growth. Using a short-term plant trial (3 months) and 4 long-term ongoing plant trials (11 months+) plant growth was assessed.

In total 87 plants were grown (comprising of 28 different tree, shrub and grass species). Out of the plants grown, 81 plants (93%) and 25 plant species (89%) successfully established and grew in rapid filtration media.

Keywords

Biomass, Bioretention, hydraulic conductivity, plant establishment, plant trial, rapid biofiltration media.

Aim

The purpose of this research was to:-

(1) determine whether New Zealand (NZ) plant species could establish and grow in a rapid filtration media (NZ Filterra) in a range of NZ climates, and to assess the growth rate of each plant species, to

(2) compare plants grown in rapid filtration media with plants grown in a council approved TP10 approved raingarden mixture, and to

(3) determine the capability of NZ plant species to sustain long-term growth in rapid filtration media.

Introduction

The upper level of hydraulic conductivity (saturated, K_{sat}) of media in bio retention treatment devices is typically limited by two main factors.

(1) Adequate contact time for pollutant removal mechanisms. The relationship between pollutant removal and K_{sat} is typically pollutant-dependant, being slowest for nitrogen and fastest for sediment and some metals (Fassman, Simcock, & Wang, 2013).

(2) Plant survival (Payne, et al., 2015) and the ability of plants to establish in the media (FAWB, 2009). The volume of water able to be extracted by plants to support growth between rainfall events.

Typical maximum K_{sat} for media are 300 mm/hr, with Australian guidance allowing higher rates in tropical areas (up to 500 mm/hr), provided plant growth can be supported (Payne, et al., 2015, Woods Ballard, et al., 2015). Recently rapid bio retention treatment devices using media with K_{sat} exceeding 2500 mm/hr have been approved for use in Washington State by Washington State Department of Ecology (WSDOE).

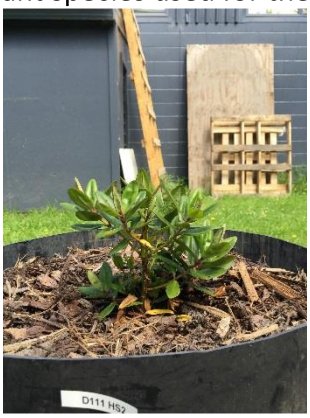
Stormwater360 in partnership with Contech USA have produced Filterra media for the New Zealand market using locally sourced materials (Hannah, et al., 2015). Five plant growth trials have been set up to evaluated the ability of local plant species to establish and grow in the media. The plants have been selected to cover a range of growth forms and rooting strategies.

Method: Short-term plant growth trial

Four native NZ plant species was evaluated over a 12-week period. The plants were groundcover species with rapid growth characteristics. Eight plants were grown in NZ Filterra media, and eight plants grown in an approved TP10 rain garden media and are shown below in Tab. 1. The native ground cover species were selected for the trial based on resilience to a wide range of soil moistures, specifically including drought, ability to quickly form a dense (weed suppressing) groundcover size, and ease of maintenance. The groundcover species selected were easily propagated varieties which grew 500 mm to 1 m height in height and thus were generally suitable for devices placed adjacent to a road.

Prior to planting, plants were saturated, then removed from their 1.7 litre plastic bags. Nearly all the potting mix was removed before each plant was carefully planted into the selected media and immediately watered to establish root/media contact. The containers were 38 cm deep and 52 cm in diameter; a coarse shredded bark mulch was then placed over the surface to a depth of about 7 cm (about 8 litres per container). The plant trial was conducted in an outdoor grassed area at the SW360 premises that was fully exposed to sunshine during the day. Plant heights were measured weekly and the change in plant biomass at the beginning and end of the 12-week period was measured for each plant.

Tab. 1. Plant species used for the short-term plant growth trial

			
Poa cita	*Hebe speciosa*	*Dianella latissima*	*Carex testacea*
Silver tussock	NZ hebe	Flax lily	Orange sedge

Watering schedule

The short-term plant growth trial began on 5th December 2015 and concluded on 22nd February 2016. Over the first 6 weeks until 18th January 2016, each container was watered with 7L of tap water and between 2-3L of stormwater bi-weekly; typically, on a Monday and Thursday morning. For the final 6 weeks (18th January 2016 onwards) plants were not watered.

The volume of water used for watering was calculated based on the amount of water that would pass through a 1.8m X 1.8m treatment unit with a 1011 m2 impervious catchment during a 2.5 mm rainfall event. For a treatment surface area of 150 mm diameter, this equated to a watering volume of 13.6L. Due to difficulties in obtaining enough stormwater for regular watering purposes, 7L of tap water and 2-3L of stormwater was used at each watering. Stormwater was sourced from sumps in the Stormwater360 carpark.

Plant assessment

The heights of the plants were measured weekly by straightening (without pulling) the plants vertically and measuring the tallest vegetation. For the Hebe speciosa, as a more rigid bush-like plant, the height and width of the plant was measured without any manipulation. The datum used for all measurements was the rim of the container. Measurements were taken by placing a straight rod across the container and extending a tape measure alongside the plant, perpendicular to the rod.

Moisture measurements were taken directly before, and 24 hours after, watering (i.e. four times a week during bi-weekly watering, and twice a week during the period when watering ceased). Moisture levels were measured at 20 cm and 30 cm depths below the rim of the container. Moisture measurements were 10-20 cm from the centre of the plant and in new locations. Each subsequent measurement corresponding with the hour positions of a clock using a Frizzell Soil Moisture Probe (Model SMP3A). The probe made measurements by sending many pulses of electricity into the media and using the returning modified signals to predict the percentage of water in the soil. The device automatically compensated for temperature variation.

Method: Long-term plant growth trial

Four long-term plant growth trials were set up and are detailed below in Tab. 2.

Tab. 2. *Summary of long-term plant growth trials (Chappell, 2013) (Macara, 2016)*

Location	Plant trial	Climate	Date planted	Median annual rainfall (mm)	Median average temperature (Celcius)			Average sunshine (hours)
					Annual	Summer	Winter	
Albany, Auckland	PT2 PT3	Subtropical	5/12/15 5/4/16	1250	15	20	11	1980
Pegasus, Canterbury	PT4	Dry arable	15/6/16	550	12	21	2	2050
Oratia, Auckland	PT5	Subtropical	22/7/16	1500	15	20	11	1980

Watering schedule

The plants were watered occasionally to simulate a base level of water and nutrients that would enter a rapid filtration treatment device in practice. Each plant in PT2 and PT3 was watered with 2 L of stormwater taken from a sump in a nearby carpark on a fortnightly basis for the first 6 months, and once every 3 months after that period. Each plant in PT4 (Pegasus, Canterbury) and PT5 (Oratia, Waitakere) was watered with 2 L of diluted Yates Thrive All-Purpose Plant Food liquid plant fertilizer each fortnight for the first 6 months, and then monthly afterwards.

Plant assessment

Plant heights were measured using the same method as for the short-term plant trial and qualitative assessments of plant health were made on a scale of 1 to 5 with 1 representing plant death, 3 stable growth, and 5 vibrant growth.

Short-term plant trial results

Plant height measurements

Changes in plant height were used to evaluate plant growth. Due to the different starting heights of the plants, a percentage difference in plant height was used to evaluate and compare growth rates.

The growth rates are presented over three date ranges:-

(3) The full 12 week period 5/12/15 to 23/02/16,

(4) the twice weekly watering period 5/12/15 to 18/01/16, and

(5) the period during which the plants were not watered 18/01/16 to 23/02/16.

Tab. 3. *Percentage height growth rates of plants during the 12 week trial*

Growth period	Day	NZFPC	NZFHS	NZFDL	NZFCT	TPPC	TPHS	TPDL	TPCT
5/12/15 to 23/2/16	1-82	29%	14%	8%	-10%	34%	31%	-5%	-15%
5/12/15 to 22/1/16	1-49	30%	6%	8%	-2%	36%	15%	-5%	-11%
22/1/16 to 23/2/16	49-82	-1%	7%	0%	-8%	-3%	16%	0%	-4%

Key: NZF=NZ Filterra media blend, TP=TP10 Approved media, PC=*Poa cita*, HS=*Hebe speciosa*, DL=*Dianella latissima*, CT=*Carex testacea*

Plant mass measurements

Changes in biomass were also used to evaluate plant growth. These measurements were obtained by extracting the plant from the media they were growing in, washing the roots of any remaining soil or gravels, and gently drying the roots using paper towels. The plants were removed from the media both at the beginning of the plant growth trial (Fig. 1.) and at the end of the experiment (Fig. 2.). The weight of the plants was measured on a scale with an accuracy of +/- 0.1g.

Tab. 4. *Plant (wet) biomass at the beginning and end of plant trial, mean of two plants per treatment*

	NZFPC	NZFHS	NZFDL	NZFCT	TPPC	TPHS	TPDL	TPCT
Initial plant weight (g)	119	97	68	26	124	74	143	23
Final plant weight (g)	118	186	136	12	197	246	257	14
Difference	-2%	+91%	+98%	-52%	+59%	+233%	+80%	-40%

Fig. 1. *Hebe speciosa removed from planter bag and had potting mix washed away at the beginning of the plant growth trial(left)*

Fig. 2. *Hebe speciosa plants removed from media at end of 12 week plant growth trial (right)*

Plant mass measurements

The plants at the end of the plant growth trial were dried and weighed to evaluate the root to shoot ratio. A high root to shoot ratio indicates that a plant has greater capacity to survive in dry and harsh conditions.

Tab. 5. Root to shoot ratio of plants

	NZFPC	NZFHS	NZFDL	NZFCT	TPPC	TPHS	TPDL	TPCT
Dry shoot mass	34	14	15	6	56	21	28	5
Dry root mass	16	38	12	0.5	16	37	27	0.9
Ratio	0.5	2.6	0.8	0.1	0.3	1.7	0.9	0.2

Media moisture content

One of the key media properties with respect to supporting plant growth was the ability of the media to retain water for plant growth. Over the course of the plant growth trial the media received water from rainfall events and watering. Using the council rain gauge at Rosedale treatment plant nearby and by converting the volume watered into an equivalent depth of rainfall, the amount of water the media received was recorded for each day. The moisture levels measured in the media at 20cm and 30cm below the rim of the container were plotted against the rainfall and watering depth.

Of interest was the field capacity and the plant available water of the media. The field capacity is the total amount of water that can be held by the media against gravity. It includes plant available water and hygroscopic water held below the nominal wilting point that is unavailable to plants. The data showed that the media was at field capacity for most of the plant growth trial, and that it was higher for the TP10 media than the NZ Filterra media.

The ability of both media to remain near to field capacity, even after weeks with no rain events or watering was due to the presence of the 75 mm mulch layer which minimized moisture loss (Simcock & Dando, 2013), and low moisture removal by plants, due to their small size.

Long-term plant trial results

Tab. 6. Summary of long-term plant growth performance by species

Location	Plant trial no.	Plant species	No. of plants	Avg height change	Qualitative assessment
Albany, Auckland	PT2	***Metrosideros Firebird Crimson Glory***	1	**41%**	**3.0**
		Hoheria populnea	1	**203%**	**3.0**
		Malicytus ramiflorus	1	**31%**	**5.0**
		Kunzea robusta	1	**49%**	**4.0**
		Chionochloa rigida	1	**54%**	2.0
		Arthropodium bifureatum	1	**72%**	**4.0**
		Phormium Green Dwarf	1	**73%**	**4.0**
		Astelia banksii	1	**96%**	**5.0**
Albany, Auckland	PT3	***Comprosma propinqua***	2	**7%**	**4.0**
		Carex secta	2	-8%	**3.0**
		Carex virgata	2	**41%**	2.5
		Sophora microphylla	2	**126%**	**5.0**
		Phormium cookianum	2	**80%**	**4.0**
		Chionochloa rubra	2	-5%	1.0
		Festuca coxii	2	-37%	1.5
		Xeronema callistemon	2	-20%	**5.0**
Pegasus, Canterbury	PT4	***Coprosma Propinqua***	3	-6%	**4.0**
		Poa cita	3	**56%**	**5.0**
		Hoheria angustifolia	3	**54%**	**4.0**
		Carex Flagelifera	3	-34%	**4.0**
		Libertia Grandaflora	3	**6%**	**4.0**
		Plagianthus regius	3	**17%**	**4.0**
		Sophora microphylla	3	-2%	**4.0**
		Pennatia corymbosa	3	-10%	**4.0**
		Pomaderris apelata	3	-6%	**4.0**
Oratia, Auckand	PT5	***Metrosideros excelsa***	5	**95%**	**4.8**
		Sophora microphylla	5	**63%**	**4.4**
		Coprosma Propinqua	5	**26%**	**5.0**
		Plagianthus regius	5	**20%**	**4.0**

Discussion

Plant establishment and growth rate

Detailed and regular measurements in the short-term plant growth trial showed vastly different growth performance of plant species in both rapid filtration media and TP10 approved raingarden media. The result observed shows the importance of plant selection in implementing a rapid bio retention system. Three native species could establish and grow in both the NZ Filterra and TP10 approved media whilst the *Carex testacea* struggled to establish in both media.

Poa cita established the best in both the NZ Filterra media and TP10 approved media after being transplanted. Over the first 6 weeks the plants increased in height by 30% and 36% respectively. Once the watering stopped, the *Poa cita* in both media stopped growing and slightly decreased in height. The stabilization of plant height is likely due to the plants reaching their mature height. The mature height of *Poa cita* in the NZ Filterra media was about 500-600 mm whilst the *Poa cita* in the TP10 media stabilized at 700 mm. Grasses that grew longer than these heights would break in the wind. *Poa cita* in the Filterra mix developed many more reproductive stems than the TP10 mix.

Hebe speciosa also successfully established in both media, however, plants in the TP10 media grew larger and faster. It was interesting to observe that the Hebe speciosa in both media grew faster during the period when watering had ceased than when being watered twice a week. The increased growth was suspected to be due to the plants having overcome transplant shock in the second half of the trial rather than drier media conditions.

The *Dianella latissima* plants also successfully established and grew in both media. New shoots could be seen growing in all four plants at the end of the plant trial. The plant grew slowly and steadily in the NZ Filterra media during the bi-weekly watering period and stopped growing (but didn't decrease in height) when watering ceased. Despite the height decrease of the plants grown in the TP10 media over both the first 6 weeks and the last 6 weeks, visually it was clear that the plants had established well in the TP10 media and were growing vibrantly at the end of the 12 week plant trial.

The *Carex testacea* plants did not establish in either media. All four plants had halved in weight by the end of the plant trial, had negligible root systems, and had died or were on the verge of dying by the end of the 12 week plant trial.

Over the 12 week period. Hebe speciosa plants in TP10 mix tripled in weight whilst the plants grown in the NZ Filterra media doubled in weight. Biomass of *Dianella latissima* were similar in both media.

Plant Resilience

Plants grown in the NZ Filterra media had a higher root to shoot mass ratio than plants grown in the TP10 media. The lower water and nutrient content in the NZ Filterra media likely encouraged the plants to allocate more resources below ground to increase the media volume accessed for water and nutrients.

Despite the lower root to shoot ratio in plants grown in the TP10 media compared with plants grown in the NZ Filterra media, the actual dry mass of roots was similar. The difference was in the mass of shoots. A direct comparison of plant root mass at the end of the plant trial is difficult to make due to the different starting sizes of the plants but it was interesting to observe that regardless of the vegetation observed growing above the surface, the roots in both the media grew to a similar mass. Hebe speciosa had the largest root mass made up of fine intertwined roots in a dense mat predominantly below the plant. The roots of the *Dianella latissima* plants in both media, but especially the TP10 media, were observed to spread extensively both laterally and vertically into the media.

Assessment Method of Long-Term Plant Health

The use of both quantitative (plant height) and qualitative (visual inspection) evaluation of long-term plant performance was informative but also showed care needed to be taken with interpreting the results. In total, 29 sets of plant species were grown in the 4 long-term plant growth trials. After trial periods of at least 11 months, 25 of the 29 plant species were shown to have established and to be growing in the rapid filtration media (Highlighted in the plant species column of Tab. 6.)

If a plant species both increased in height and looked healthy visually (18 out of 29), the plant had established well in the NZ Filterra media. There were however several instances where the plant height had decreased but clearly the plant was well established and growing vibrantly (7 out of 29). These plants, upon being transplanted from a rich potting mixture into a lean rapid filtration media, likely adapted to a lower nutrient environment by growing new leaves and shoots to a lower height.

If was difficult to visually assess the health of plant species with deciduous characteristics as these plants had shed all their leaves and looked barren. Visual inspection during Summer would be more useful for these plant species.

Out of the 29 sets of plants grown in the long-term plant trials, two plant species were not able to establish in the rapid filtration media and plant height and visual inspections clearly showed this.

Conclusion

The plant growth trial successfully demonstrated that NZ native plants can establish and grow in a rapid infiltration media (NZ Filterra) with a hydraulic conductivity of 2500 mm/hr. In the short-term plant trial, three out of the four plant species trialed, were able to establish and grow in the media. In ongoing long-term plant trials, 27 out of the 29 plant species trialed successfully established in the rapid filtration media and were continuing to grow after 11 months or longer.

The plant trials have conclusively shown that a wide variety of plants are able to establish and grow in the NZ Filterra rapid filtration media. As expected, some plant species grew better than others. Research is on-going at Stormwater360 to better understand and identify the key characteristics of a plant species that enable survival and growth in rapid filtration media.

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