Root and Shoot Development in Ornamental Shrubs: The Influence of Compacted Soil and Altered Root Geometry

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Abstract

Root systems are expected to 'perform' in a variety of difficult and stressful urban soil environments. Experiments were conducted to simulate compacted soil conditions and altered rhizosphere geometry to determine how these factors affect root development and subsequent plant quality. Comparisons were made across three common landscape shrubs; *Philadelphus* cv. Aureus, *Philadelphus* cv. Belle Etoile and *Euonymus* cv. Silver Queen. A factorial experiment investigated three levels of compaction (control, medium and high compaction) across three soil types (organic, clay and sand). High compaction was detrimental to root extension in clay and organic soils, but had no effect in sand. Reductions in shoot extension corresponded to restricted root development. In a second experiment artificially altering the geometry of the rhizosphere was implemented by growing plants in 1/ tall, narrow columns, 2/ shallow trays or 3/ conventional pots. Despite plants being grown in identical volumes of media and provided with similar irrigation regimes, total root weight and root branching was reduced in the narrow columns, with again a corresponding reduction in top growth. The results have implications for how plants respond to stresses related to compacted soils and unusual soil profiles. The data confirm previous studies in that there are significant negative factors encountered with typical urban soils, but under certain scenarios there may also be some beneficial effects with respect to plant morphology. These will be discussed.

INTRODUCTION

Plants in city locations are particularly prone to poor states of health due to difficult growing conditions encountered in the urban environment (Jim, 1998). Two common problems affecting plants grown in urban areas are compacted soil and restricted soil/rhizosphere volume to facilitate normal root development. Soil compaction results from activities during building construction and other infrastructure development. Soils are intentionally compacted to help stabilise the foundations of buildings, and adjacent areas often become compacted through the use of heavy machinery. Compacted soil is frequently associated with poor soil structure (loss of 'crumb structure'), reduced pore volume (reduced drainage capacity and poor aeration, Lipiec et al., 2003), loss of fertility and low organic matter content (Soane and Ouwerkerk, 1994) and a high bulk density (Alberty et al., 1984). Plants react to compaction through physiological and morphological modifications, resulting in reduced biomass production, lower stomatal conductance, slower rates of cell expansion which in turn contribute to reduced root growth and shoot extension (Sadras et al., 2005). Lack of cell activity too, impacts on hormonal synthesis and this may contribute to a 'vicious circle' with hormones such as abscisic acid (ABA) being activated and reducing growth further.

An alternative to planting in the parent soil is to locate plants in containers, designed planters, or tree pits, where a better quality growing medium can be supplied. The downside of these systems is that their limited physical volume, may also constrain root development and access to water / nutrients. Root morphology in container grown plants is often different to that of those grown 'in the field'; for example increased competition between individual roots for space and resources and these root dynamics can affect shoot growth (NeSmith and Duval, 1998). Where root growth is restricted / constrained there can be corresponding alterations in nutrient and water uptake (Yong et al., 2010), photosynthetic activity, leaf size and reduced shoot extension and a more compact plant habit (Poorter et al., 2012). In addition, container shape, dimension and volume of substrate can ultimately influence plant longevity (Al-Zalzaleh, 2009).

This research investigated the effects of soil compaction and container dimensions on plant establishment, root development and growth habit, using two common landscape shrubs (*Philadelphus* and *Euonymus*) as model species, with different genotypes of *Philadelphus* employed to examine intra-species comparisons. Model systems were employed in semi-controlled environments (glasshouses) to mimic conditions found in *in situ* urban soils.

MATERIALS AND METHODS

Experiment 1: The influence of bulk density and soil type (sand v clay v organic) on root dynamics and shoot development

This experiment evaluated the effect of increased compaction (bulk density) on plant root and shoot development across three contrast soil types; namely organic loam (John Innes No. 1 – 'Seedlings and Young Plants') – 'organic', clay soil - 'clay' and horticulture grit and sand - 'sand'. Three genotypes were used: - *Philadelphus coronarius* 'Aureus', *Philadelphus coronarius* 'Belle Etoile' and *Euonymus japonicus* 'Silver Queen'. 'Loose' friable soil was inserted into pots (3 Litre, 15.9cm diameter x 20.5cm height) and either not compacted – 'Controls' or compacted with a 2.5kg Proctor hammer – 'Medium' bulk density or a 4.5kg Proctor hammer - 'High' bulk density. Total original volumes of friable soil used per pot were Controls (all soils = 3 L), Medium (organic = 4.5 L, sand = 3.5 L and clay = 4.0 L) and High (organic = 5 L, sand = 4.5 L and clay – 4.5 L). These volumes being compressed to fit in with the final 3 L volume of the pots.

Controlled release fertilizer (5 g Osmocote, Pro 17N:11P:10K:2Mg, Scotts, USA) was applied as a top-dressing feed to each pot to help avoid any nutrient deficiency, especially in the sand and clay soils .After the soils were compacted, a rooted cutting was placed in each pot, carefully creating a hole for the rootball without causing undue disturbance (i.e. radically altering the bulk density) of the media below / around it. Plants were carefully watered in and hand watered from there on as required (saucers being used under pots to allow any 'run off' to be re-absorbed). Plants were grown from 6th May 2013 to 5th August 2013. Air temperature in the glasshouse were recorded every 3 minutes using Tiny tag Data Logger. Plant height and fresh / dry weight was recorded at the end of the experiment. Two way analysis of variance (ANOVA) was conducted to investigate the interaction between the severity of compaction and types of media on plant growth.

Experiment 2: The effect of rhizosphere volume / geometry on shoot growth and root development, when irrigation application was consistent between pot designs.

This experiment was conducted in a glasshouse from 20th May 2013 until 29th July 2013. Liners of *P.* cv. Aureus, *P.* cv. Belle Etoile and *E.* cv. Silver Queen were potted on into 3 different geometrically designed containers; 1 litre conventional pot (15 x 22 x 3 cm), shallow tray (22.5 x 16.5 x 5.5cm lbh) and tall column (4.1 d. x 80 cm h.). All of the containers were filled with 1 litre of Sinclair peat-based growing medium. There were three positional blocks within the glasshouse. In each block, each species was represented by 3 different container designs with 5 replicate plants for each design. After potting up, plants were left to establish for two weeks before controlled irrigation was implemented. Once established, each plant was watered manually with 1 litre of water on each occasion. This was applied with a measuring cylinder, and water was applied slowly to ensure each container design could accommodate the volume without excess run-through, or spilling over the lip of the container.

The initial data of plant height and branch number were recorded on 3rd June 2013, and plants were then recorded weekly for the next 9 weeks, at which points they were harvested. Plants were assessed for height, total branch number, number of branches ⩾ 10 cm; number between 5 and 10 cm and number ⩽ 5 cm, shoot and root dry weight.

RESULTS

Experiment 1. The influence of bulk density and soil type (sand v clay v organic) on root dynamics and shoot development

Growth tended to be greatest in the two *Philadelphus* cultivars in the Control organic soil treatment (Table 1). Compressing the organic medium, suppressed height significantly and growth in the high bulk density treatment was characterised by reduced internode length and leaf area (Table 1). Increasing bulk density in the clay, also tended to suppress growth in *Philadelphus*, but this was not the case with sand, where actually increasing bulk density (Medium in *P.* cv. Aureus, and High in *P.* cv. Belle Etoile) showed some growth advantages. With the exception of the clay treatment, increasing bulk density appeared to have relatively little effect on the *Euonymus* height (Table 1). Root and shoot biomass tended to reflect the trends for plant height, being significantly greater for the organic controls in *P.* cv. Aureus (Fig. 1) and *P.* cv. Belle Etoile (Fig. 2) than other treatment combinations; but greatest with the Medium and Highly compacted sand in the *Euonymus* (Fig. 3).

Experiment 2. The effect of rhizosphere volume / geometry on shoot growth and root development, when irrigation application was consistent between pot designs.

Total biomass for *P.* cv. Aureus, *P.* cv. Belle Etoile and *E.* cv. Silver Queen was greatest in conventional pot grown plants and of the two non-conventional container shapes, growth parameters were frequently better in the tray system than columns, although differences were not necessarily significant (Fig. 4). Both trays and columns reduced the total number of branches in *Euonymus* compared to pots (as well as within the different size categories, Table 2). The differences were less marked in *Philadelphus*, although there was a trend of reduced branching in trays and columns with *P.* cv. Aureus.

DISCUSSION

Both degree of compaction and soil type had a strong influence on growth parameters, although there were some variations in response between species. In the more vigorous *Philadelphus*, increasing the bulk density of the growing medium radically reduced growth; this being the case even for the relatively 'open' medium of the organic soil. Reduced growth corresponded to a more compact growth habit, as demonstrated by shorter internode lengths. Growth in the denser clay was also reduced, even in control plants, suggesting that the naturally high particle density – poorer pore structure associated with this soil type was constraining growth. In contrast, growth of *Philadelphus* was also poor in the sand, but the nature of this medium tends to be more open and well-aerated, so growth reduction here may be due more to water relations or nutrient levels / distribution. Despite the frequent watering the free draining nature of the sand may have caused localised drying, perhaps induced root signals that closed the stomata. (Davies et al., 2005) reported that plant maintained its shoot water status by inducing long-distance chemical signal when experienced soil drying which resulting in constraint shoot growth. Growth in *Euonymus* was generally less vigorous than *Philadelphus* overall, but in contrast was optimised in the high density sand treatments. The better draining or aeration characteristics of the sand may have suited the *Euonymus* more than other genotypes, and increasing relative density in this medium perhaps aiding water retention between irrigations. Interestingly, this result challenges the notion that organic based growing media are always superior for plant growth.

One of the more startling results of the research was the manner in which container geometry influenced growth (without changes in media volume or apparent density). Plant growth was inhibited in *P.* cv. Aureus and *E.* cv. Silver Queen by encouraging root growth down a narrow column. Alterations to nutrient and water availability cannot be ruled out as potential reasons for this; i.e. more rapid drainage, limited capillary rise or localised nutrient deficiency at the top of the column being possible reasons. Alternatively inhibition of lateral root development due to the narrow diameter of the column may have interfered with resource acquisition, or reduced the supply of root synthesised hormones that may also affect top-growth development. Growing plants in the shallow tray was detrimental to biomass accumulation and the development of new branches in *E.* cv. Silver Queen, but had less effect in the *Philadelphus* cultivars. The reasons for this are unclear, but may again relate to moisture retention between irrigations, as the relatively large exposed surface area and the medium shallow depth may have increased evaporation and decreased the water holding capacity, respectively.

CONCLUSIONS

Increasing bulk density tended to reduce growth (as depicted by height, internode length and leaf area) in organic and clay soils but was less evident in sand. This confirms previous work on problems associated with compacted (Kirkegaard et al., 1992), but is somewhat surprising for the more openly-structured organic soil, although results here may be an artefact of altered water retention properties (e.g. loss of macropores) more so than increased physical resistance to root penetration. Paradoxically, increasing the bulk density of the open sand may aid water retention, by inhibiting the naturally free-draining properties to some degree. Further research is required to test these assumptions. On the other hand, it is clearly evident from the experiment that container design / geometry is having a marked effect on plant morphology (irrespective of the volume of container available to exploit), with growth being optimised with a conventional pot design. This has implications for the dimensions and dynamics of planters used in urban situations and further work is warranted to illustrate the mechanisms by which rhizosphere geometry influences root and shoot development in landscape plants. .

ACKNOWLEDGEMENTS

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Tables

Table 1. Plant height, internode length and leaf area for 3 species grown in 3 different levels of compaction and media. P≤0.005, d.f:27.

		Height (cm)			Internode Length (cm)			Leaf Area (cm2)		
		Con	*Med*	*High*	*Con*	*Med*	*High*	*Con*	*Med*	*High*
	Organic	30.4	20.8	12.1	3.0	2.6	1.9	31.1	28.1	16.1
***P*. cv. Aureus**	*Sand*	6.5	10.2	5.1	1.2	1.6	1.1	10.7	17.0	7.5
	Clay	17.2	5.6	4.5	2.1	1.0	0.9	32.9	8.9	7.4
	LSD	**8.36**			**0.78**			**10.91**		
	Organic	41.2	23.8	19.7	2.9	2.5	1.9	17.9	15.8	13.5
***P*. cv. Belle Etoile**	*Sand*	13.6	13.9	19.2	1.7	1.4	1.7	10.0	7.8	8.3
	Clay	16.8	17.3	10.4	1.8	1.9	1.4	10.2	8.8	4.9
	LSD	**5.74**			**0.74**			**5.47**		
	Organic	18.3	17.4	18.8	1.6	1.4	1.3	6.9	7.4	4.8
***E.* cv. Silver Queen**	*Sand*	16.8	20.5	18.5	1.5	1.5	1.4	4.4	3.1	4.1
	Clay	15.7	8.3	10.4	1.2	1.1	1.2	5.2	3.1	3.3
	LSD	**3.85**			**0.30**			**1.54**		

Table 2. Total number of branches, number of branches over 10cm, between 5 to 10cm and below 5cm for 3 species in 3 different container types.

		Total no. of branches			No. of branches over 10cm			No. of branches between 5 t0 10cm			No. of branches below 5cm		
		Pot	*Tray*	*Column*	*Pot*	*Tray*	*Column*	*Pot*	*Tray*	*Column*	*Pot*	*Tray*	*Column*
***P.* cv. Aureus**		6.73	5.67	5.00	2.07	1.93	0.07	2.87	2.07	2.13	2.00	1.73	2.80
	LSD	***1.92***			***0.63***			**1.09**			**1.34**		
***P*. cv. Belle Etoile**		4.87	5.27	4.33	2.70	2.70	1.80	0.80	1.10	1.50	1.30	1.50	1.10
	LSD	**1.58**			**0.65**			**0.90**			**1.31**		
***E.* cv. Silver Queen**		9.00	4.27	3.53	2.13	1.33	1.13	2.00	1.53	0.80	4.60	1.40	1.60
	LSD	**2.18**			**0.49**			**0.90**			**2.44**		

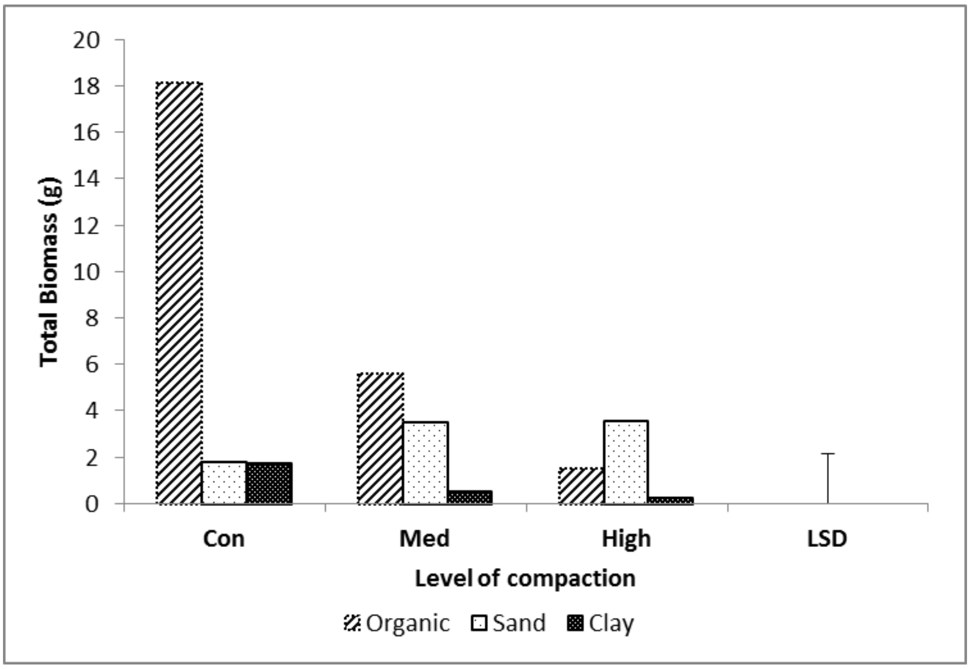

Fig. 1. Total biomass for *P.* cv. Aureus in three different levels of compaction and media. $P \leq 0.005$, d.f: 27. LSD: 2.129

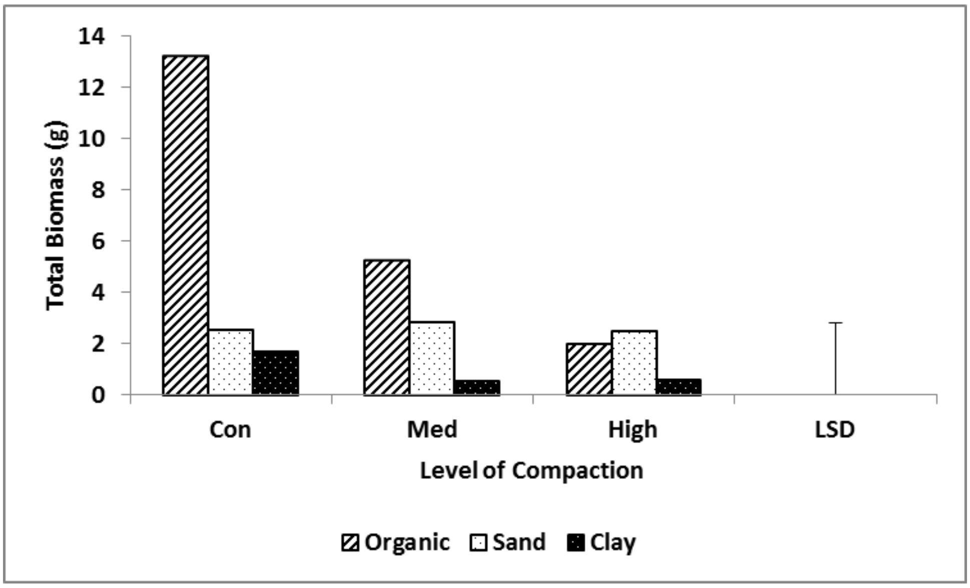

Fig. 2. Total biomass for *P.* cv. Belle Etoile in three different levels of compaction and media. $P \leqslant 0.005$, d.f: 27. LSD: 2.802

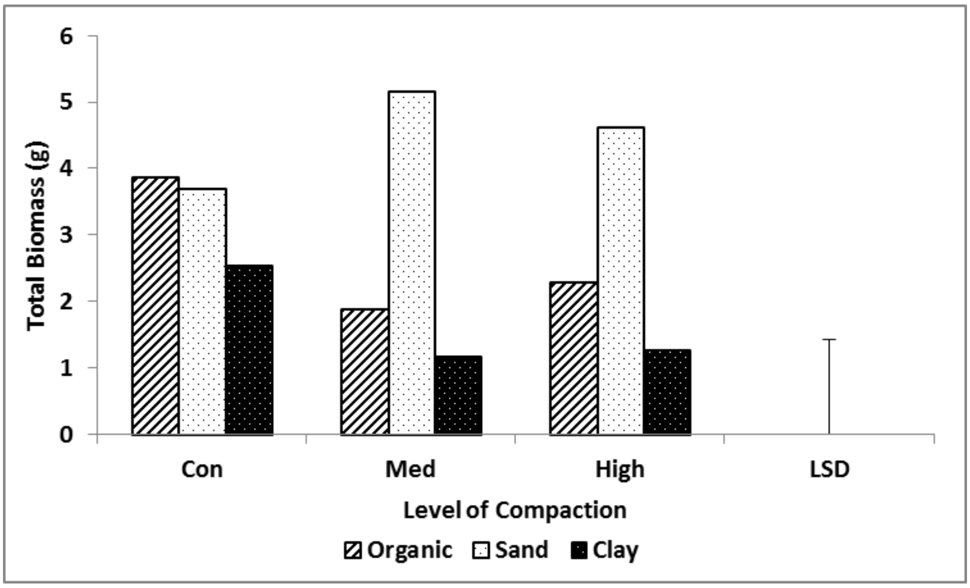

Fig. 3. Total biomass for *E.* cv. Silver Queen in three different levels of compaction and media. P⩽0.005, d.f: 27. LSD: 1.430

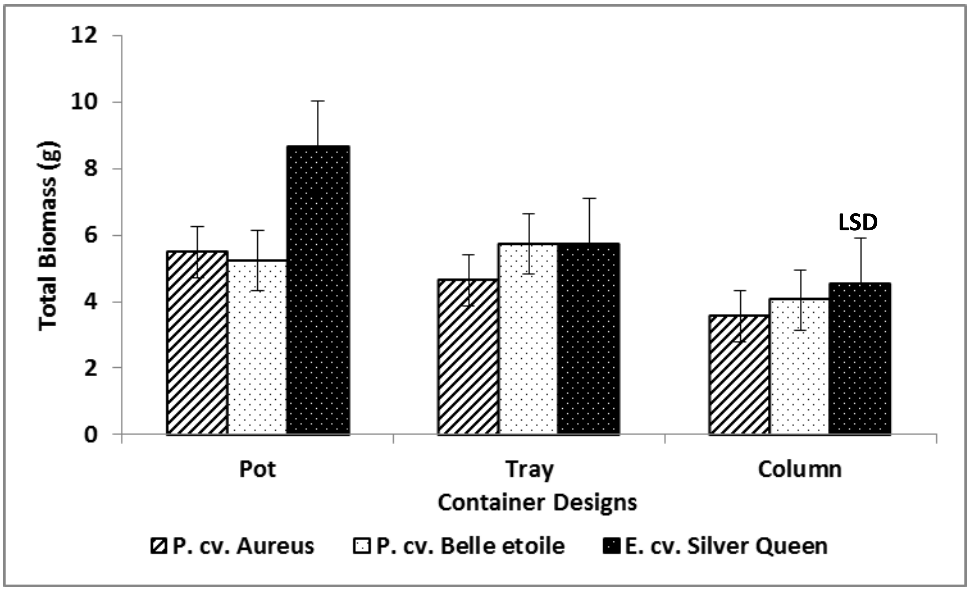

Fig. 4. Total biomass for *P.* cv. Aureus, *P.* cv. Belle Etoile and *E.* cv. Silver Queen in three different container designs. P⩽0.005, d.f: 42. LSD: (*P.* cv. Aureus = 0.763; *P.* cv. Belle Etoile = 0.906 and *E.* cv. Silver Queen = 1.387)