Moderate Increases in Substrate Packing Density Can Improve Petunia Root Development

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ABSTRACT. Greenhouse horticulture relies on manual labor for plug transplanting, which is subject to variability in substrate packing density. Little research exists on the effect variable substrate packing density has root morphological development. Petunia hybrid 'Supertunia Honey' plugs were grown in peat-based substrates packed at four densities (0.08, 0.10, 0.12, and 0.14 g·cm^{-3}). The results indicated that root development was improved with moderately increased substrate density.

The greenhouse industry requires efficient production lines to ensure maximum profitability. While some operations are beginning to automate substrate potting and transplanting, most still rely on individuals to operate machines and participate in commercial potting lines. During substrate filling and plug transplant, human error or variation can occur which results in inconsistently filled containers and can impact plant quality. This is important considering plant quality and uniformity is a primary concern across North American growers (Fields et al. 2023).

Data regarding substrate packing density (D_b) on commercial potting lines is sparse in the literature (Alred et al. 2024). Owen and Lopez (2019) found that substrate compaction via container stacking can negatively affect rooting in some species. Regardless, upon potting, several factors can impact initial D_b, including human variation, substrate moisture, and composite composition. Substrates that are heavily compressed or packed into a container at too great a density can influence plant growth due to changes in air-filled porosity and subsequent water storage (Kormanek et al. 2023). Pore modifications can also alter the ability of root proliferation. Thus, developing a better understanding of how different packing densities influence plant growth is relevant to the industry. The objective of this research was to investigate whether different packing densities impacted plant development and salability by evaluating a linear increase from light to heavy filling.

Materials and methods

SUBSTRATE PREPARATION AND ANALYSIS. A compressed Canadian Sphagnum peatmoss substrate (Pro-Mix LP-15; Premier Tech Horticulture, Richer, Canada) was expanded and hydrated. A standard filled container was determined to be 0.08 g·cm^{-3}. Four substrate packing density treatments, 0.08, 0.10, 0.12, and 0.14 g·cm^{-3}, were developed to increase typical density linearly. Packing densities were calculated by using the hydrated D_b of a 1.7-L container filled with a peat-based substrate at different densities, drying the material, and plotting a linear regression equation (R^2 = 0.9988). Thus, containers were either lightly packed by tapping containers on the bench three times (e.g., 0.08 g·cm^{-3}; 450-g container^{-1}) or hand pressed until corresponding weights were measured (0.10 g·cm^{-3} = 550-g container^{-1}; 0.12 g·cm^{-3} = 650-g container^{-1}; 0.14 g·cm^{-3} = 750-g container^{-1}). Seven containers of each density were packed.

GROWTH TRIAL. One *Petunia* hybrid 'Supertunia Honey' plug was transplanted into each container. Plants were watered once a week for 14 d with 200 mL of water with a 1.8 L·h^{-1} spray stake (Netafim, Fresno, CA, USA). Thereafter, all containers were irrigated twice weekly at the same irrigation rate (200 mL/irrigation). All plants received an additional fertigation with 200 mL of 200 ppm N liquid fertilizer with micronutrients (20N–20P_2O_5–20K_2O; Peters Professional Fertilizer, Summerville, SC, USA) every 7 d.

Growth indices [(plant height + plant width + perpendicular width)/3] of all plants were measured weekly, as was via SPAD meter (SPAD 502 Plus; Spectrum Technologies, Inc., Aurora, IL, USA). Fully opened flower count for each plant was measured weekly. Plants were grown for 46 d, after which, plants were photographed, and shoot material was severed at substrate surface and dried at 70 °C for 7 d. In five replicates per treatment, roots were washed of substrate particles and analyzed via an open-source root imaging software (RhisoVision; Seethepalli et al. 2021); root systems were suspended in a thin layer of water, carefully spread, and imaged (iPhone 13 Pro; Apple, Cupertino, CA, USA). Images were scanned with TurboScan (Piksoft Inc., Piedmont, CA, USA) and converted to a JPG format. Batch analysis was used, and metrics were summed aside from average diameter. Root morphology measurements included total root length (centimeters), average diameter (millimeters), surface area (centimeters squared), and dry biomass (grams).

DATA ANALYSIS. All data with associated statistics were analyzed in JMP Pro (18.0.0; SAS Institute, Inc., Raleigh, NC, USA) using analysis of variance to identify any significant statistical differences across the means of the responses previously described. If significant, post hoc Tukey's honestly significant difference test (α = 0.05) was used to separate means across

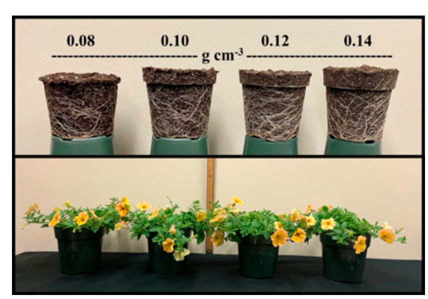

Fig. 1. Representative photographs of petunia plants grown in different substrate packing densities.

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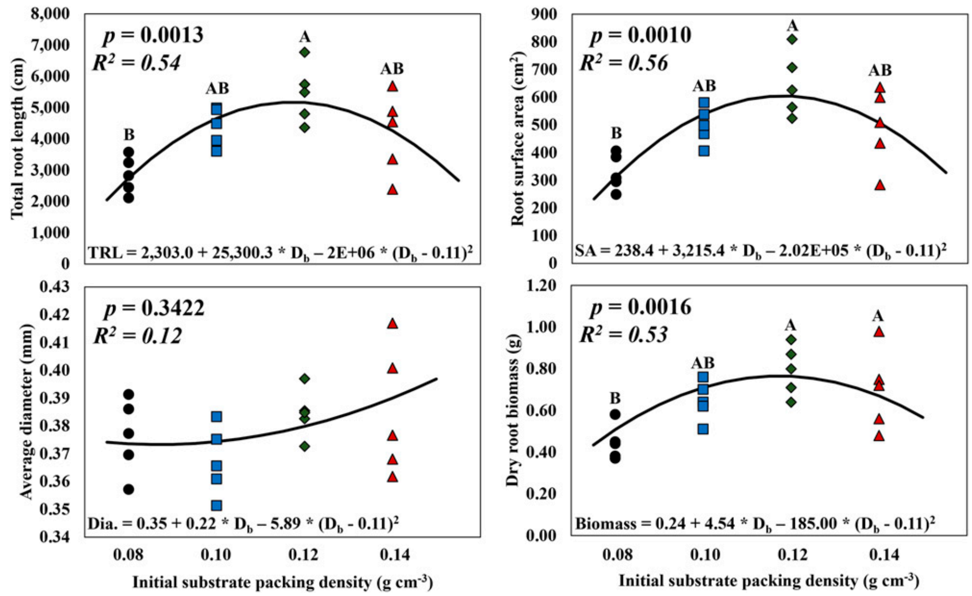

Fig. 2. Root morphological measurements of petunia plants grown in different substrate packing densities. *P* values indicate probability of a quadratic relationship and are significant at the ($\alpha = 0.05$) level. Letters indicate statistical differences across density treatments using Tukey's honestly significant difference analysis if analysis of variance was significant at the ($\alpha = 0.05$).

substrate treatments. Quadratic relationships were detected and used (when compared with linear relationships) if there was significance at the ($\alpha = 0.05$) level or if the R^2 value was greater.

Results and discussion

Plants grown across different substrate packing densities were similarly sized ($P = 0.4476$) with comparable greenness (i.e., SPAD; $P = 0.4808$). Statistically no differences were found with flower development ($P = 0.0736$); however, plants grown in denser substrate profiles contained on average greater flower count. In any event, there were no negative relationships found with shoot quality and substrate compaction, and all plants were considered salable by authors (Fig. 1). Regarding root morphology, there were quadratic relationships detected between substrate density and total root length ($P = 0.0013$), root surface area ($P = 0.0010$), and dry root biomass ($P = 0.0016$; Fig. 2). Uniquely, average root diameter was statistically insignificant ($P = 0.3422$; Fig. 2).

The relationships regarding increased substrate compression and root development contrast data reported by Owen and Lopez (2019), where the authors found that compressed substrates via stacking containers decreased root development. The denser substrates in this study likely increased root–substrate contact (Tracy et al. 2013), resulting in three mechanisms: 1) greater moisture and mineral nutrient uptake (Stirzaker et al. 1996); 2) faster elongation rates (Schmidt 2011); and 3) more compact soils (or substrates), leading to decreased porosity and increased water storage, which may have increase lateral root initiation and fine root development (Iwata et al. 2013) and contributed to the greater surface area and biomass accumulation.

In field soils, it is well known that high D_b can have negative effects on root development (Singh and Sainju 1998). Most mineral soil studies examine root systems on a continuum of increasing D_b ranging <1.8 g·cm^{-3} and report reduced root biomass (Foil and Ralston 1967; Rosolem and Takahashi 1998), lengths (Logdson et al. 1987), and distribution (Shierlaw and Alston 1984). However, it is difficult to compare soilless-grown plants with varying substrate D_b with previous literature because soilless substrates differ from mineral soils significantly (i.e., ~5× lower densities), little research has examined greenhouse plant growth when grown in "dense" soilless substrates, and research is sparse regarding soilless-grown roots and their morphology in response to physical properties (Criscione and Fields 2024). Considering these research limitations, assumptions regarding plant growth cannot be confidently made without further investigation.

Conclusion

The results of this study provide insight on consistent substrate packing density and its possible impact on plant growth. The data herein suggest that compressing peat-based substrates slightly by hand before transplant may improve root development in the container, with little to no impact on shoot development. However, more research is needed to understand commercial potting line variations (e.g., personnel, substrate type, belt and hopper speed, pot type and size, plant species) and its influence on plant growth responses.

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