THESIS

INVESTIGATION OF SUBSTRATE SELECTION AND FINISHING PROTOCOLS FOR NURSERY CONTAINER PRODUCTION OF 13 PLANT TAXA NATIVE TO THE SOUTHWESTERN UNITED STATES

Submitted by

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ABSTRACT

INVESTIGATION OF SUBSTRATE SELECTION AND FINISHING PROTOCOLS FOR NURSERY CONTAINER PRODUCTION OF 13 PLANT TAXA NATIVE TO THE SOUTHWESTERN UNITED STATES

Nursery-produced native plant taxa are a tool for habitat restoration, and their use extends beyond wildlife areas as urban residents seek to create wildlife corridors. Water conservation concerns and understanding of pollinator decline further motivates use of native plants in cultivated and designed landscapes. Furthermore, increasing awareness around degradation of peatlands, drives consumer interest in sustainably produced plant material using peat-alternative substrates. Growers attempt to meet the demand for native plant material, but protocols for growing these taxa, which are not adapted to thrive in peat-based substrates, are limited. Without finishing protocols for sizing up propagules to retail size, growers, who are limited by time and resources, amend peat-based substrates using trial and error in hopes of achieving favorable growing outcomes.

We identified grower practices through a survey of nationwide Plant Select® growers. Based on survey results, we evaluated survivability and plant growth in response to partially replacing peat-based substrate with sand, field soil, a microbial-inoculated compost (MIC), and a green waste compost (GWC). Our results indicated that plant growth response to these substrates is taxon specific. However, only one of the 13 taxa evaluated resulted in a significantly higher plant growth index (PGI) increase in the control group. Thus, our findings suggest that 12 of the investigated taxa may respond to peat-reduced substrates during the finishing period without significant negative impacts on PGI or dry weight.

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TABLE OF CONTENTS

ABSTRACT……………………………………………………………………………………….ii
ACKNOWLEDGEMENTS…………………………………………………………………………iii

Chapter 1. Impact of Substrate on Three Woody Plant Taxa Native to the Southwestern United States

1.0.1 Summary.. 1
1.1 Introduction..2
1.2 Materials and Methods.. 3
1.2.1 Grower Survey...3
1.2.2 Research Locations..4
1.2.3 Substrate Selection...5
1.2.4 Plant Material...7
1.2.5 Data Collection... 8
1.2.6 Statistical Analysis..9
1.3. Results and Discussion.. 9
1.3.1 Grower Survey Responses..9
1.3.2 Growth Response and Survivability in *Arctostaphylos* x *coloradensis*......................... 10
1.3.3 Growth Response and Survivability in *Arctostaphylos* x *coloradensis* ‘Chieftain’.........12
1.3.4 Growth Response and Survivability in *Rhamnus smithii*... 14
1.4 Conclusion...16
Literature Cited.. 18

Chapter 2. Impact of Substrate on Ten Herbaceous Taxa Native to the Southwestern United States

2.0.1 Summary.. 20
2.1 Introduction..21
2.2 Materials and Methods.. 23
2.2.1 Grower Survey, Research Locations, and Substrate Selection.................................. 23
2.2.2 Plant Material...23
2.2.3 Data Collection... 24
2.2.4 Statistical Analysis..26
2.3 Results and Discussion.. 26
2.3.1 Grower Survey...26
2.3.2 Growth Response and Survivability in *Andropogon gerardii* ‘PWIN01S’......................27
2.3.3 Growth Response and Survivability in *Eriogonum umbellatum* var. *aureum* ‘Psdowns’...30
2.3.4 Growth Response and Survivability in *Geum triflorum*.. 33
2.3.5 Growth Response and Survivability in *Glandularia bipinnatifida*................................. 35

2.3.6 Growth Response and Survivability in *Liatris ligulistylis* 38
2.3.7 Growth Response and Survivability in *Mirabilis multiflora* 42
2.3.8 Growth Response and Survivability in *Penstemon linarioides* ssp. *coloradoensis* 'P014S' 46
2.3.9 Growth Response and Survivability in *Penstemon pinifolius* 'P019S' 49
2.3.10 Growth Response and Survivability in *Penstemon pseudospectabilis* 52
2.3.11 Growth Response and Survivability in *Penstemon rostriflorus* 56
2.4 Conclusion 59
Literature Cited 61
Appendix Grower Survey Questions and Taxa 64

Chapter 1. Impact of Substrate on Three Woody Plant Taxa Native to the Southwestern United States

1.0.1 Summary

Woody plant taxa native to Colorado and the Southwestern United States hold an important place in the landscape due to their ability to provide habitat and forage for native fauna and their lower-maintenance cultural requirements once established. Nursery container production of these taxa allow for availability of plant material for restoration and landscaping in urban and peri-urban areas, but producing this plant material can be difficult for growers.

We investigated current grower practices through a nationwide survey of Plant Select® growers. We then replicated these practices through growing three woody plant taxa in peat-reduced substrates amended with sand, field soil, a microbial-inoculated compost (MIC), and a green waste compost (GWC) and compared this with growth of plants grown in a standard peat-based substrate.

Our results indicated that using sand, MIC, or GWC as an amendment did not have detrimental effects on plant growth, though it did not significantly increase plant growth for any of the taxa evaluated in this study. Addition of field soil corresponded with similar or decreased growth in all three taxa, and was significantly decreased in *Arctostaphylos* x *coloradensis* ‘Chieftain.’

Overall, the woody plant taxa evaluated, which can be slow growing, were tolerant of peat-alternative amendments and did not show decreased growth in response to reduction of peat as a substrate.

1.1 Introduction

In the semi-arid mountain west, native woody plant taxa play an important role in cultivated landscapes (Bożek et al., 2023). Many of these taxa are able to survive in dry settings where landscape water use is regulated and restricted and vegetation is needed to help manage stormwater in rain events (Dropkin et al., 2016). Once established, supplemental irrigation needs are minimal for many of these taxa.

Native woody plant taxa have the capacity to provide food, forage, and habitat for a range of native insects, birds, and mammals, many of which have an obligate relationship with these plants (Rottler et al., 2015). By incorporating these taxa into our urban landscapes we can provide corridors that connect wildland areas that have become wildlife islands (Tallamy, 2017).

A number of native woody plants provide year-round interest in landscapes through evergreen foliage, textured bark, and berries or cones. While woody plants add aesthetic value to the landscape, Brzuszek et al. (2007) suggest that landscape architects choose native plants for their hardiness and low-maintenance growing habits.

Similarly, Potts et al. (2002) assert that surveyed green industry professionals in Colorado perceive that consumers are interested in landscaping with native plants to create habitat and support native fauna rather than for aesthetic value. Yet, in the same survey, some green industry professionals expressed frustration that sometimes native plants look like “sticks in a pot,” clearly referring to the challenges of producing slow-growing woody plant material. The four plant taxa listed as best sellers by landscape architects were all woody plant taxa and three of four best-selling taxa identified by nurseries and garden centers were woody plant taxa.

Growers face challenges in container production of woody plant taxa including sourcing and storing plant material for asexual propagation, lack of tested best management practices for production (i.e. finishing protocols), and low rooting rates (Rupp et al., 2011). Furthermore, some taxa, like *Arctostaphylos* x *coloradensis*, are easy to propagate but are then susceptible to pressures from root rot pathogens like *Phytophthora* spp. (Borland and Bone, 2007).

Peat-based substrates are often selected by growers for finishing woody plant material because it is economically viable to source and is engineered for optimum physical and chemical characteristics (Barrett et al., 2016). Growing concerns over the ecological degradation of peat-lands and the sustainability of peat harvesting (Alexander et al., 2008) has contributed to consumer awareness of peat consumption in the horticultural industry. Behe et al. (2010) identified purchasers of woody plant material as better targets for ecofriendly products and production practices compared to other groups of purchasers.

Growers have expressed the need for tested protocols on substrates that support excellent nursery container production of woody plant species, which can be a challenge to overwinter in peat-based substrates (Potts et al., 2002). Our first objective was to identify how growers are currently finishing their woody plant materials in containers, specifically in regards to substrate selection. We then replicated these finishing methods and evaluated whether they resulted in increased above-ground growth during the finishing period.

1.2 Materials and Methods

1.2.1 Grower Survey

In order to evaluate current methods of growing woody plant taxa native to the Southwestern US, a survey was developed in collaboration with a consultant from Plant Select®. The survey received exempt status under IRB protocol 19-9581H. The survey consisted of six questions (Appendix 1) and referred to 20 taxa, five of which were woody plant taxa (Appendix 1). 95 Plant Select® growers were contacted via email in December 2019. After the initial email, growers were emailed an additional two times in January 2020, reminding them to take the survey.

1.2.2 Research Locations

Replicates were grown in containers in an outdoor, uncovered field setting. In 2020 and 2021, space was used at the Colorado State University Horticulture Center (40.565, -105.085) located in Fort Collins, Colorado, USA. This location is in USDA Plant Hardiness Zone 5b (-26.1 to -23.3 °C) (USDA, 2012) and is located at an elevation of 1,523 m (4,996 ft). In 2022, space was used in the Duckwood Community Garden (38.708, -104.715) in Fountain Creek Regional Park in Fountain, Colorado, USA. This location is in USDA Plant Hardiness Zone 6a (-23.3 to -20.6 °C) (USDA, 2012) and is at an elevation of 1,708 m (5,604 ft).

These locations are along the Front Range of Colorado in a semi-arid environment and are roughly equidistant from the Denver Metro area. Climate conditions were similar during growing seasons, though some growing seasons experienced more precipitation, independent of site (Table 1).

Table 1. Minimum, maximum, and mean temperature and total precipitation for each month from May to August of each experimental period in 2020, 2021, and 2022. Source: NOWData, National Oceanic and Atmospheric Administration

Month	Year	Site	Min. Temp. (°C)	Max Temp. (°C)	Mean Temp. (°C)	Total Precip. (mm)
May	2020	Fort Collins, CO, USA	7.6	22.9	15.3	64.8
June	2020	Fort Collins, CO, USA	12.2	29.4	20.8	33.8
July	2020	Fort Collins, CO, USA	14.8	31.7	23.2	3.8
August	2020	Fort Collins, CO, USA	13.8	32.3	23.1	12.2
May	2021	Fort Collins, CO, USA	6.7	20.3	13.4	140.3
June	2021	Fort Collins, CO, USA	12.9	30.2	21.6	12.2
July	2021	Fort Collins, CO, USA	15.6	31.7	23.6	16.5
August	2021	Fort Collins, CO, USA	13.8	30.7	22.2	16.3
May	2022	Colorado Springs Area, CO, USA	7.3	22.8	15.1	51.3
June	2022	Colorado Springs Area, CO, USA	12.5	28.1	20.3	34.8
July	2022	Colorado Springs Area, CO, USA	15.6	31.8	23.7	135.9
August	2022	Colorado Springs Area, CO, USA	14.7	29.5	20.1	46.2

1.2.3 Substrate Selection

A control and four experimental treatments were used to assess plant response to substrates commonly used by growers. Sunshine LC1 by Sun Gro Horticulture (Agawam, Massachusetts, USA) was used as the control. This product contains Canadian sphagnum peat moss, coarse perlite, dolomitic lime, and a wetting agent.

Treatments contained Sunshine LC1 and amendments at a percent by volume (Table 2). Comand™ is a proprietary compost that contains enzyme-producing microbes, including Actinobacteria, and was used in the microbial-inoculated compost (MIC) treatment. Ecogro™ is a proprietary green waste compost (GWC) primarily composed of yard waste, food waste, and brewery residuals and was the amendment in the green waste compost (GWC) treatment. Comand™ and Ecogro™ were produced by A1 Organics (Eaton, Colorado, USA). The field soil treatment contained clayey soil collected in Fort Collins, Colorado. The sand treatment contained coarse mason sand. Substrates were commercially mixed and delivered by Golf and Sport Solutions (La Salle, Colorado, USA).

Table 2. Composition of substrate amendment treatments in 2020, 2021, and 2022.

Treatment	Base	Amendment	Reason	Cost per yard (USD)
Control	100% Sunshine LC1	-	Industry standard	277.53
Microbial-Inoculated Compost (MIC)	85% Sunshine LC1	15% Comand™	Incorporate beneficial microorganisms	244.15
Green Waste Compost (GWC)	70% Sunshine LC1	30% Ecogro™	Locally available, consistent production	205.67
Field Soil	90% Sunshine LC1	10% field soil	Texture closer to native soil, potential for beneficial microorganisms	253.18
Sand	70% Sunshine LC1	30% sand	Improve drainage	218.57

Percentages of amendments added to treatment groups were decided based on discussion with a Plant Select® consultant and feedback from respondents in the survey. Osmocote Plus 15-9-12 (Scotts Miracle-Gro Company, Marysville, Ohio, United States) was used as a topdressing in all treatments four weeks after propagules were transplanted into #1

(2.37 L) containers. It was added at a rate of 22.18 mL per #1 (2.37 L) container, according to the recommendation on the label. These containers were manufactured by Growneer (Chongming County, Shanghai, China).

Physical and chemical analysis of substrate treatments was conducted by the Colorado State University Soil, Water and Plant Testing Lab in Fort Collins, Colorado, USA (Table 3).

Table 3. Physical and chemical analysis of substrate treatments.

Treatment	Texture	pH	EC (mmhos/cm)	N (ppm)	P (ppm)	K (ppm)
Control	Loam	6.8	0.2	0.1	1625.0	2304.0
MIC	Loam	6.6	0.5	0.1	69.0	79.3
GWC	Loam	7.4	0.4	0.1	106.7	157.8
Field Soil	Loam	6.9	0.4	0.5	37.7	40.3
Sand	Loam	6.7	0.3	0.1	18.6	24.2

1.2.4 Plant Material

Three native woody plant taxa were selected for evaluation. *Arctostaphylos* x *coloradensis* was selected along with a cultivar of this hybrid, *Arctostaphylos* x *coloradensis* ‘Chieftain.’ *Arctostaphylos* x *coloradensis* ‘Panchito’ was included in the 2022 growing season, but is not included in the analysis due to the limitations of using only one year of data in the statistical model. A deciduous shrub, *Rhamnus smithii*, was also selected for use in this study. Plant propagules were purchased from Fort Collins Wholesale Nursery (Fort Collins, Colorado, United States).

The experimental growing period spanned a 12-week finishing period, defined as the period of time from when a propagule is transplanted into a larger container where it reaches a size acceptable for retail. This was repeated over three growing seasons in 2020, 2021, and 2022. Propagules of were transplanted into five replications of the five treatments per taxon in

#1 (2.37L) containers during May of each growing season. Irrigation was provided daily by hand using a watering wand during the first six weeks of each experimental period and was tapered to every other day for the remaining six weeks.

1.2.5 Data Collection

An independently replicated complete block design was used, randomizing substrate treatments within each taxon. Containers were placed in rows of two so that all containers could be accessed for data collection without moving them. Five replicates per treatment per taxon were used for a maximum of 25 experimental units, or plants, per taxon per growing season, and a maximum total of 75 plants per taxon over the course of the study. This amounted to a maximum of n=15 for each treatment within each taxon throughout the duration of the study. However, only 16 plants could be sourced for *Rhamnus smithii* for the 2020 growing season and so there were three replicates per treatment and four replicates in the control group in 2020.

Plant growth measurements were collected every two weeks over the 12-week finishing period. These measurements consisted of the width at the widest point of the canopy (W1) averaged with the perpendicular width (W2), and averaged again with the overall plant height (H). These three measurements were used to calculate a Plant Growth Index, or PGI, using the following equation: $(((W1+W2)/2)+H)/2$.

At the end of the 12 week finishing period, change in PGI was calculated by subtracting the initial measurement from the final measurement for each replicate. If plants died during the growing season, their change in PGI was calculated as zero. However, if the plant remained alive, but decreased in size, a negative change in PGI was calculated. Dead plants were not removed from the analysis because the effect of substrate on plant survival was being evaluated.

1.2.6 Statistical Analysis

Statistical analysis was conducted in RStudio version (RStudio, Inc., Boston, Massachusetts, USA). A linear mixed-effects model was used to analyze PGI data using substrate treatment as a fixed effect and year as a random effect to account for variations in site, weather, and the person watering the plants.

ANOVA was used to compare variation within and among treatments and a multiple testing adjustment was made for post-hoc pairwise comparisons using Tukey's Honest Significant Difference (HSD) test in the emmeans package. Substrate treatments were compared within each taxon, but taxa were not compared to each other.

1.3. Results and Discussion

1.3.1 Grower Survey Responses

Survey response rate was 24% with 23 of 95 growers responding. The majority of responding growers (78%) had been growing Plant Select® taxa for five years or more and the remaining growers had been growing Plant Select® taxa for 1-5 years. Most growers who produced woody plant taxa also produced herbaceous taxa. However, one grower only grew woody plant taxa.

Of the woody plant taxa listed in the survey, 34% of growers had experience growing *Arctostaphylos* x *coloradensis* 'Panchito,' 30% had grown *Arctostaphylos* x *coloradensis*, and 17% had grown *Arctostaphylos* x *coloradensis* 'Chieftain.' The deciduous woody plant taxa on the survey, *Jamesia americana* and *Rhamnus smithii*, had only been grown by 13% and 4% of growers, respectively. This is perhaps because propagation protocols refer to growing these species from seed instead of cuttings and caution that *Jamesia americana* is prone to damping off and *Rhamnus smithii* requires pre-treatment (Plant Select, 2020).

It is interesting that the woody plant taxa on the survey were grown by fewer growers than the herbaceous taxa. Given the findings of Potts et al. (2002) that woody plant taxa were among best sellers in the green industry, our findings suggest that fewer growers produce woody plant material, perhaps indicating that they are more challenging to grow in nursery container cultivation.

Notably, when growers were asked what tips they had for growing these taxa, they primarily focused on growing media and amendments. When growing *Arctostaphylos* x *coloradensis* and related cultivars, growers mentioned using peat/perlite potting mixes and adding sand, bark, or lava rock. Adding microbial inoculants or compost was mentioned as well as using time-release fertilizer. Fewer growers had experience growing *Jamesia americana* and mentioned that they used custom growing mixes made on site. No growers had tips for growing *Rhamnus smithii*, potentially indicating that it is either difficult to propagate or difficult to find plant material for cultivation.

Some growers mentioned Plant Select® propagation protocols in their responses for *Arctostaphylos* x *coloradensis*. These protocols are available on the Plant Select® website on a password-protected page for growers.

Due to grower focus on growing media and amendments in the survey responses, it was decided that the treatments for this study would involve reproducing some of the methods that growers are using to determine whether that substrate had effects on plant appearance in containers at the end of the finishing period. This is when the plants would typically become available in a retail setting.

1.3.2 Growth Response and Survivability in *Arctostaphylos* x *coloradensis*

Where the native ranges of *Arctostaphylos uva-ursi* and *Arctostaphylos patula* overlap on Colorado’s Uncompahgre Plateau, these taxa naturally hybridize (Ackerfield, 2022). This hybrid is called *Arctostaphylos* x *coloradensis* and further selections have been made in cultivation, mainly for leaf size and shape.

Arctostaphylos x *coloradensis* is an evergreen shrub with reddish bark. It has become popular in the landscape setting due to its drought tolerance and its success in part-shade and on slopes. It grows two feet tall and spreads over five feet wide. It requires excellent drainage, otherwise leaves and stems turn black and the plant dies. Growers note that in container production of this taxon, *Phytophthora* root rot is common (Rupp et al., 2011).

Flowers are short-lived and inconspicuous, quickly becoming small berries. In cultivated landscapes this plant is typically not selected for its phenological characteristics, but rather for its leaves and bark, which provide year-round interest. *Arctostaphylos* x *coloradensis* and its cultivars are considered lower maintenance, requiring no pruning and minimal water after establishment.

Survivability of *Arctostaphylos* x *coloradensis* was excellent across all treatments over the 12-week finishing period repeated in three growing seasons. Two replicates in the GWC treatment died (Figure 1). *Arctostaphylos* x *coloradensis* grew slowly, less than doubling over the 12-week finishing period. The change in PGI was very similar between all replicates across treatments in *Arctostaphylos* x *coloradensis*. The field soil and GWC treatments had a somewhat lower increase in PGI over the 12 week period (Figure 1). No significant differences were observed between treatment groups, suggesting that this taxa could tolerate peat-alternative substrates without compromising plant growth.

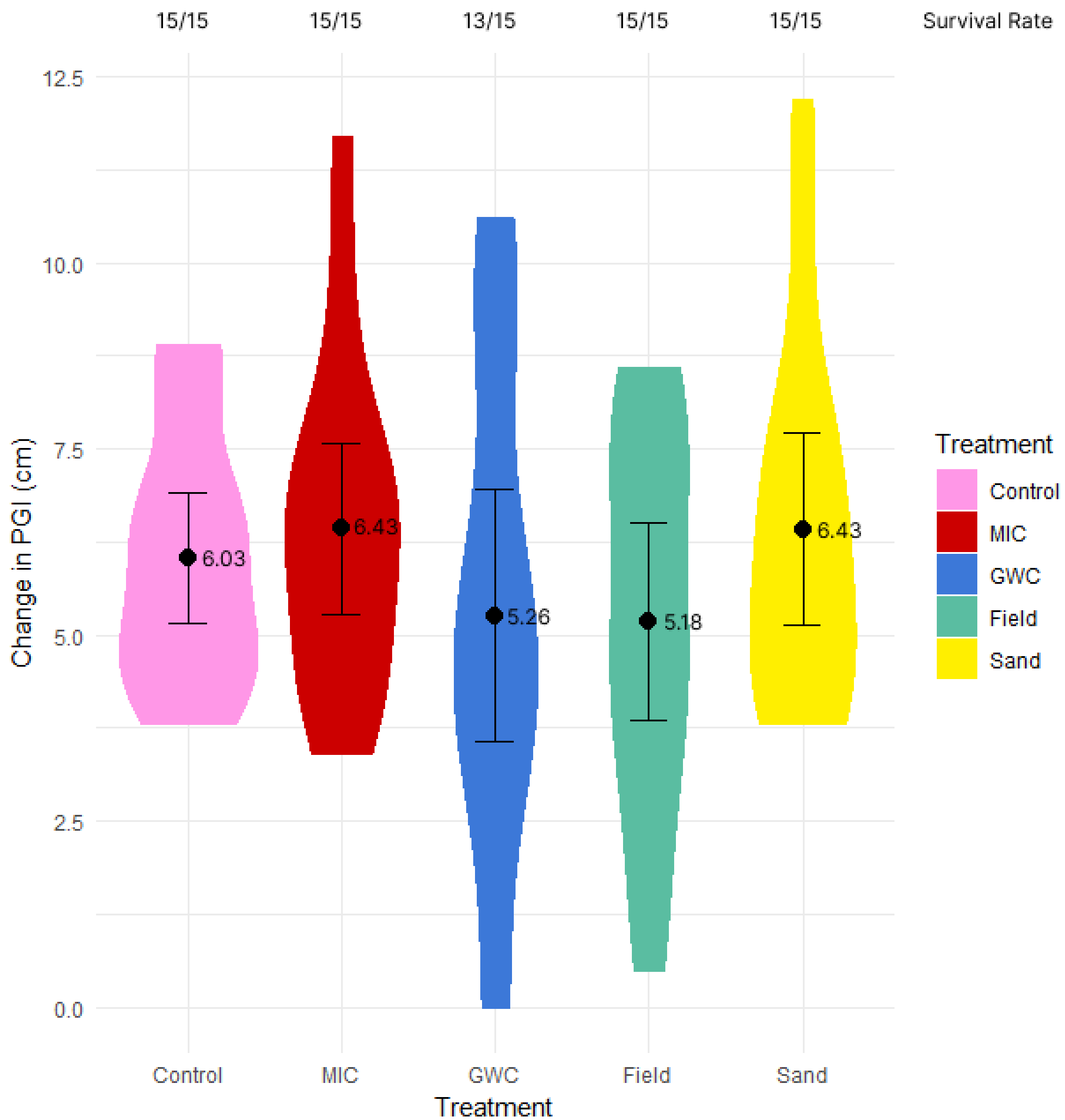

Figure 1. Change in plant growth index (PGI) over the 12-week finishing period in three growing seasons (2020, 2021, 2022) for *Arctostaphylos* x *coloradensis*. MIC = microbial-inoculated compost. GWC = green waste compost.

1.3.3 Growth Response and Survivability in *Arctostaphylos* x *coloradensis* 'Chieftain'

Arctostaphylos x *coloradensis* 'Chieftain' showed good survivability across all treatments. One replicate died in the sand treatment. The highest mortality was seen in the native soil treatment where two replicates died (Figure 2).

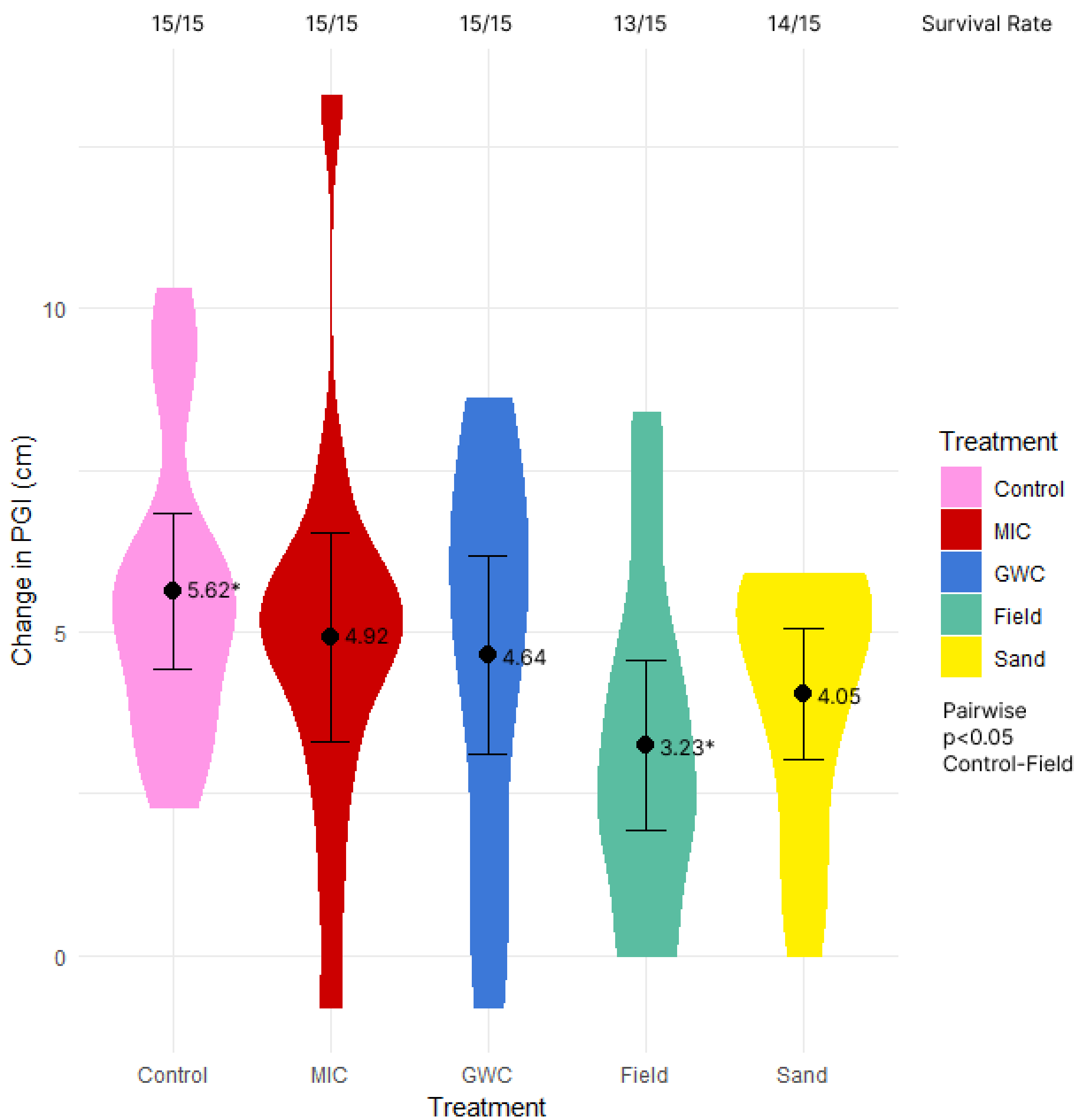

Figure 2. Change in plant growth index (PGI) over the 12-week finishing period in three growing seasons (2020, 2021, 2022) for *Arctostaphylos* x *coloradensis* 'Chieftain.' MIC = microbial-inoculated compost. GWC = green waste compost.

The highest change in PGI for *Arctostaphylos* x *coloradensis* 'Chieftain' was seen in the control group and was significantly higher ($p<0.05$) than the field soil treatment. The addition of field soil impacted drainage rates of the growing media in that treatment. A head of water was still visually evident in the containers in the field soil treatment after containers with other substrate treatments had drained. Excellent drainage is clearly required for *Arctostaphylos* x *coloradensis* ‘Chieftain’ to thrive. Plants in the field soil treatment showed symptoms of stress including chlorotic leaves, stunted growth, and death.

Average increases in PGI ranged from 3.23 to 5.62 cm, showing that this taxon grows very slowly. This represents less than 50% increase in PGI during the finishing period across all treatments. Given these very small increases in growth, it is imperative that growers optimize growth to increase the marketability of their crop. It is perhaps not surprising that this taxon, a selection of a naturally occurring hybrid, grows well in the industry-standard peat-based substrate. Without this success, it is unlikely this selection would have been introduced into the horticultural industry.

1.3.4 Growth Response and Survivability in *Rhamnus smithii*

Rhamnus smithii is a thornless shrub that can grow eight to ten feet high and wide and is densely covered with dark green leaves, which turn yellow in the fall (Colorado State University Extension, 2018). While it does produce attractive berries that provide food for birds and other wildlife, these berries typically do not appear while the plant is going through container cultivation.

Rhamnus smithii is typically selected for use in the landscape because it provides privacy and is low maintenance, requiring little water once established. It does not need to be pruned, though it tolerates pruning and can be shaped into a small, multi-stemmed tree (Plant Select, 2002).

Survivability rates during the finishing period were adequate for *Rhamnus smithii*, though no treatment resulted in 100% survival. The control, MIC, GWC, and sand treatments each had one replicate die. The field soil treatment had two replicates die (Figure 3). Mortality rates this high could be the reason growers are not as interested in this taxa.

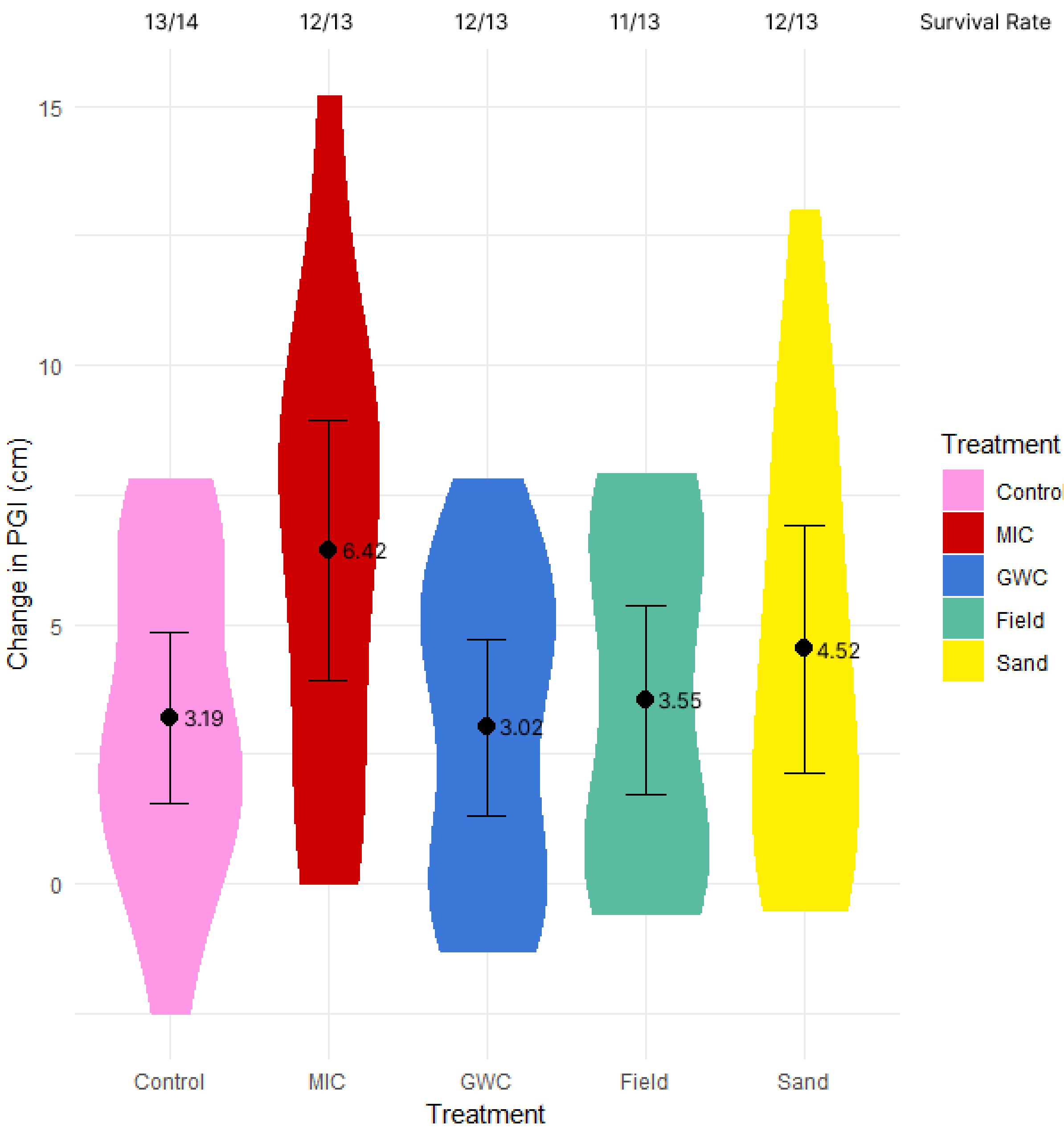

Figure 3. Change in plant growth index (PGI) over the 12-week finishing period in three growing seasons (2020, 2021, 2022) for *Rhamnus smithii.* MIC = microbial-inoculated compost. GWC = green waste compost.

The greatest mean increase in PGI for *Rhamnus smithii* was seen in the MIC treatment. Notably, this was the only treatment where no replicates showed a decrease in growth. The GWC treatment, containing the other compost evaluated in this study, resulted in a smaller increase in growth, slightly smaller on average than the control. While the nutrient analysis of these two treatments were similar, the primary difference is the microbial inoculation during the composting process.

Propagules of this taxon often show considerable stress response to cultural changes, with curling and thickened leaves. Propagules may only have three or four leaves present at the time of transplanting. The toll that abiotic stressors can have on *Rhamnus smithii* in cultivation, as opposed to the other evergreen taxa evaluated in this study, are considerable, and this taxon is susceptible to transplant shock (Plant Select, 2020).

Actinobacteria can aid in plant stress response through production of hormones and enzymes, improving availability of nutrients, and facilitating osmotic balance (Rao et al., 2022). Propagules of this taxon showed visual signs of abiotic stress at transplanting, and presence of beneficial microbes like Actinobacteria may have facilitated propagules in the MIC treatment to overcome this stress and have a comparably higher increase in growth.

Across all treatments, *Rhamnus smithii* less than doubled in size over the 12-week finishing period and thus, small increases in growth can be noticeable to growers and consumers. No statistically significant differences in PGI were observed between treatments for this taxon, and *Rhamnus smithii* may tolerate cultivation in peat-alternative substrates, particularly those that contain beneficial microbial content.

1.4 Conclusion

Woody plant species are often slow-growing and, therefore, growers strive to increase plant survivability and maximize plant growth. Adding substrate amendments resulted in comparable final products for taxa examined in this study. However, adding field soil, even in a quantity as small as 10% by volume, corresponded with significantly decreased growth of *Arctostaphylos* x *coloradensis* ‘Chieftain’ compared to the control. This was likely due to decreased drainage rates, as water visibly pooled on the surface of growing media in this treatment longer than in the other treatments. Though the texture of the field soil added was a clayey soil, it was only added to this treatment at 10% by volume, and a texture analysis of the substrate treatment resulted in loam.

Adding sand at 30% by volume did not have any detrimental effects on taxa in this study. Many of these taxa prefer soils with good drainage, potentially influencing growers to add sand to their growing media. While this addition may not harm these taxa, this also did not provide any clear benefit in terms of growth. These containers became heavy and depending on grower operations and transport costs, adding sand may not be economical for these taxa.

Composts vary greatly in physical and chemical characteristics, as well as in microbiology. Adding a microbial-inoculated compost (MIC) resulted in slightly increased PGI in deciduous woody taxon, *Rhamnus smithii*, though this was not significant. The evaluated evergreen woody taxa seemed to be less affected by adding either compost type.

The three studied taxa were not significantly impacted by the amendments used in this study, with the exception of significant decrease in PGI of *Arctostaphylos* x *coloradensis* ‘Chieftain’ in the field soil treatment. They show potential for being cultivated in peat-alternative substrates. Growers could consider reducing peat and substituting it with more sustainably produced and harvested materials, without detrimental effects on woody plant growth. This may improve marketability with consumers looking to support growers using more sustainable practices.

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Chapter 2. Impact of Substrate on Ten Herbaceous Taxa Native to the Southwestern United States

2.0.1 Summary

Herbaceous taxa of plants native to Colorado and the Southwestern United States play an important role in the landscape as residents try to find drought-tolerant replacements for common ornamental plants. Container cultivation of these native plant taxa provide unique challenges for growers who are used to producing non-native ornamentals that thrive in peat-based substrates.

We surveyed Plant Select® growers nationwide to determine current methods for propagation of native plant taxa. We then compared these methods to evaluate growth response and biomass of plants grown in peat-reduced substrates amended with sand, field soil, a microbial-inoculated compost (MIC), and a green waste compost (GWC). We compared these treatments with plants grown in an industry-standard peat-based substrate.

While plant response to these treatments was taxon-specific, many taxa responded with decreased growth and biomass to the addition of field soil. *Penstemon linarioides* ssp. *coloradoensis* ‘P014S’ and *Penstemon pinifolius* ‘P019S’ showed increased survivability when faced with disease pressure with the addition of MIC. Adding sand corresponded with increased biomass for taxa with modified stems that are adapted to low soil moisture content.

Overall, many taxa did not show significant differences in plant growth and biomass when peat was substituted with compost, sand, or field soil. This may indicate that the herbaceous native plant taxa evaluated in this study could tolerate peat-alternative substrates in nursery container production.

2.1 Introduction

Native plants are emerging as a popular option for use in landscape settings, and as awareness of native plants increases, consumers are more likely to purchase native plant material (Zadegan et al., 2008). As homeowners and landscapers in the Southwestern US adapt their landscapes to comply with water reduction guidance and legislation, they can struggle to find plant material that can survive in these conditions. Urban residents are becoming aware of pollinator decline (Hall and Martins, 2020) and are considering how landscaping with native plants allows them to play a role in supporting pollinator health. These plants are often selected for landscapes, in part, because they can increase biodiversity and create habitat linkages (Tallamy, 2017).

A number of barriers prevent the demand for native plants from being met (Peppin et al., 2010). Many nurseries and garden centers do not carry native plants because they are concerned about their marketability (Brzuszek and Harkess, 2009). After a standard 12-16 week finishing period, native herbaceous plants may not be in bloom, unlike showier non-native ornamentals. Their foliage alone may not attract consumers to select them. Furthermore, some native plant taxa can show great variability in vegetative and phenological characteristics, which can lead to operational and marketing challenges for growers and retailers. When growers strive for uniformity of plant material through selection and vegetative propagation, this may impact the genetic diversity of habitat created in urban landscapes, which is a primary motivator of many consumers who purchase native plant material.

Furthermore, herbaceous native plants require different care and maintenance than conventional nursery crops (Rihn et al., 2022). Producers may not be aware of how to manage these unique water and fertilization requirements or their systems may not allow for adaptation to these needs. Other non-native ornamental taxa may have production protocols that growers can follow, but these protocols are not often available for lesser-known or regionally-used native taxa, which may not thrive in peat-based potting media.

The horticultural industry uses peat in container production due to its physical properties that lead to favorable growth outcomes for the majority of nursery crops (Schmilewski, 2008). The US Geological Survey estimated that the apparent consumption of peat in the United States in 2018 was 1.67 million metric tons. Peat occurs in wetland ecosystems, and in some regions, it is being harvested at rates that may not be sustainable (Chapman et al., 2003). Growers are likely to select peat as a soilless substrate for nursery cultivation even when more sustainable replacements are available due to its abundance, its relatively low cost, the low transport costs due to low bulk density, and the availability of engineered products that don't require additional mixing or treatment (Barrett et al., 2016).

Even growers who specialize in growing native plant material can struggle to grow it (Bujak, 2015). In the absence of protocols, producers experiment on their own, and growers are limited in time and resources to do their own testing (Potts et al., 2002). Composts are highly variable in physical and chemical composition, which can influence plant growth response. Plants tolerate higher amounts of green waste compost (GWC), or compost made from plant material, as they are potted up into larger containers, while seedlings are more likely to be adversely affected (Burger et al., 1997). This may demonstrate the potential for incorporating higher amounts of GWC during the finishing period, rather than during the propagation period, as a replacement for peat-based potting media.

Other producers, aware of the need that many native plants have for soils with good drainage, may add sand as a component of potting media, and while this may increase drainage rates, it can also decrease overall pore space, air-filled pore space, and water buffering capacity (Goh and Haynes, 1977). Sand and field soil are sometimes added to reduce the cost of potting media, or to increase the bulk density. The proportion at which growers use these constituents in peat-based substrates varies greatly, and the desired impact on plants is not always achieved, sometimes leading to plant mortality. This further demonstrates the need for finishing protocols for growers in order to meet the demand for native plant material in the green industry.

In order to develop finishing protocols for growers for container production of herbaceous taxa native to the Southwestern United States, our first objective was to identify what taxa are being grown and what practices growers are using in their production. Our second objective was to reproduce and evaluate these methods, particularly with regard to substrate selection.

2.2 Materials and Methods

2.2.1 Grower Survey, Research Locations, and Substrate Selection

This survey was performed concurrently with the woody plant finishing trial outlined in Linfield and Bousselot (in review) Chapter 1. With support from a Plant Select® consultant, a short survey of six questions (Appendix 1) was developed to identify current practices that growers use in production of 15 herbaceous Plant Select® taxa native to the Southwestern US. IRB exempt status was obtained under IRB protocol 19-9581H. The survey was sent to a total of 95 Plant Select® growers across North America via email in December 2019, and the growers received two reminder emails in January 2020.

These methods were then evaluated for 10 herbaceous plant taxa from the survey. The site locations and substrate selection (Table 2) were the same. All materials, other than plant material, were the same as in the concurrent woody plant trial.

2.2.2 Plant Material

Based on availability of plant material from Plant Select® growers, 10 taxa were selected. One graminoid, *Andropogon gerardii*, was selected in addition to nine forbs. Mat-forming forb taxa included *Eriogonum umbellatum* var. *aureum* ‘Psdowns’, *Geum triflorum*, *Glandularia bipinnatifida*, *Mirabilis multiflora*, *Penstemon linarioides* ssp. *coloradoensis* ‘P014S’, and *Penstemon pinifolius* 'P019S'. Upright forbs included *Liatris ligulistylis*, *Penstemon pseudospectabilis*, and *Penstemon rostriflorus*.

Penstemon species were purchased in plug trays from Gulley Greenhouse and Nursery (Fort Collins, Colorado, United States). *Liatris ligulistylis* was purchased from Fort Collins Wholesale Nursery (Fort Collins, Colorado, United States). All other taxa were purchased from Harlequin's Gardens (Boulder, Colorado, United States).

The period of time from when a propagule is transplanted in a larger container until it will reach a size acceptable for retail is referred to as the finishing period. The finishing period in our study spanned 12 weeks and was repeated over three growing seasons in 2020, 2021, and 2022. Propagules were transplanted into five replications of the five treatments in #1 (2.37L) containers during May of each growing season. These containers were manufactured by Growneer (Chongming County, Shanghai, China). Daily irrigation was provided by hand using a watering wand and after the initial six weeks, irrigation was tapered to every other day during the remaining six weeks.

Plant material from replicates of *Penstemon pinifolius* 'P019S' that were exhibiting symptoms of a root rot pathogen were tested by the Colorado State University Plant Diagnostic Clinic (Denver, Colorado, USA) using visual observation, microscopy, media culture, PCR, and Sanger sequencing.

2.2.3 Data Collection

Substrate treatments were randomized within each taxon using an independently replicated complete block design. Each taxon had its own randomized complete block design and taxa were not compared to each other. Replicates were not moved during the study. Five replicates per treatment per taxon were used for a maximum of 25 plants per taxon per growing season, and a maximum total of 75 plants per taxon over the course of the study. After the completion of the experimental period, spanning three growing seasons, a maximum of n=15 was used for each treatment within each taxon.

Penstemon pseudospectabilis could not be sourced in 2022 and *Andropogon gerardii* ‘PWIN01S’ could not be sourced in 2021. As a result, only 50 plants, or 10 per treatment, are included in the analysis for these taxa. In 2021, only 10 plants of *Geum triflorum* were sourced so there are 60 plants or 12 per treatment of this taxon included in the analysis. In 2020 one plant of *Liatris ligulistylis* was missing, and, thus, the control group had 14 plants while all other treatments have 15 plants. Similarly, one plant of *Eriogonum umbellatum* var. *aureum* ‘Psdowns’ was missing in 2022 and the control group had 14 plants, or one fewer than the other treatments. In 2021 all replicates of *Penstemon linarioides* ssp. *coloradoensis* ‘P014S’ perished within a two-week period and were not included in the analysis. As a result, there are 50 plants of this taxon from two years of data rather than all three.

Every two weeks, plant growth measurements were recorded. These measurements consisted of the width at the widest point, a perpendicular width, and the height. These three measurements were used to calculate a Plant Growth Index, or PGI, using the following equation: (((W1+W2)/2)+H)/2.

The initial PGI was subtracted from the final measurement to calculate the change in PGI over the 12-week finishing period for each replicate. A PGI of zero was recorded for replicates that died during the finishing period, but if the replicate decreased in size and remained alive, a negative change in PGI was recorded. Dead replicates were included in the analysis because substrate treatment may have contributed to plant mortality.

Above-ground biomass was harvested at the end of the 12-week finishing period in each of the three growing seasons. This plant material was dried at 70°C for 72 hours, and dry weights were measured.

2.2.4 Statistical Analysis

RStudio version (RStudio, Inc., Boston, Massachusetts, USA) was used for statistical analysis and a linear mixed-effects model was used to analyze PGI and dry weights. The model used substrate treatment as a fixed effect and year as a random effect to account for variations in site, weather, and the person watering the plants.

ANOVA was used to compare variation within and among treatments and a multiple testing adjustment was made for post-hoc pairwise comparisons using Tukey's Honest Significant Difference (HSD) test in the emmeans package. Taxa were not compared to each other.

2.3 Results and Discussion

2.3.1 Grower Survey

A 24% response rate was observed with 23 of 95 growers completing the survey. While 22% of growers had been growing Plant Select® taxa for five years or less, the majority (78%) had more than five years of experience growing Plant Select® taxa. The herbaceous taxa on the survey were all produced by more growers than the woody plant taxa on the survey, though the least frequently grown herbaceous taxa, *Eriogonum wrightii* var. *wrightii, Sorghastrum nutans* 'Thin Man', and *Verbena bipinnatifida* were grown by 35% of growers and tied with the most frequently grown woody plant taxa, *Arctostaphylos* x *coloradensis* 'Panchito.' Note that *Verbena bipinnatifida* was placed in the *Glandularia* genus during the course of this study and will be referred to as *Glandularia bipinnatifida* elsewhere in this study.

Over half of responding growers produced *Penstemon pseudospectabilis* (65%), *Liatris punctata* (57%), *Geum triflorum* (52%), *Penstemon linarioides* ssp. *coloradoensis* 'P014S' (52%), *Penstemon mensarum* (52%), and *Penstemon rostriflorus* (52%). The sole graminoid in the survey, *Andropogon gerardii* 'PWIN01S', was grown by just under half of the responding growers (48%). Given that this taxa is easy to grow and that plant material is readily available, this perhaps indicates a perception within the green industry that there is less of a demand for grasses. This is consistent with the findings of Brzuszek et al. (2007) which identified that grasses were ranked lower than woody plants and flowering herbaceous plants for specification in landscapes by landscape architects.

Growers noted that peat-reduced substrates including bark, sand, and aggregate material such as calcined clay, lava rock, and perlite were used with the intention of improving drainage for *Andropogon gerardii* 'PWIN01S,' *Calylophus serrulatus* 'Prairie Lode,' *Eriogonum wrightii* var. *wrightii*, *Geum triflorum*, *Heterotheca jonesii* x *villosa* 'Goldhill', *Liatris punctata*, *Penstemon linarioides* ssp. *coloradoensis* 'P014S', *Penstemon mensarum*, *Penstemon pinifolius*, *Penstemon pseudospectabilis*, *Penstemon rostriflorus*, *Sorghastrum nutans* 'Thin Man,' *Glandularia bipinnatifida*, and *Zinnia grandiflora* 'Gold on Blue.'

Some growers mentioned adding beneficial microbes, though the growers that used these practices recommended it across all taxa they grew; their use of this technique was not taxon specific. Other growers added nutrient solutions in the form of kelp solutions and compost tea, while others added slow-release granular fertilizers.

With a large grower focus on substrates and amendments, treatments were designed to reproduce current grower practices in order to see how these taxa responded to these protocols.

2.3.2 Growth Response and Survivability in *Andropogon gerardii* 'PWIN01S'

Andropogon gerardii 'PWIN01S' is a warm-season grass that grows up to six feet tall. It is used for ornamental purposes in the landscape setting due to its form, seed heads, and leaves that turn reddish-purple in the fall. Growers propagate this taxa through division, and this bunch grass has rhizomes that can extend up to 10 feet in the landscape (Owsley, 2011).

There was 100% survival among all treatments for *Andropogon gerardii* 'PWIN01S.' Acceptable increase in growth was observed among all treatments and the change in PGI did not vary greatly among treatments. The field soil treatment had the smallest increase in growth, though it was not significantly smaller than the change in PGI observed in other treatments (Figure 4). Because this taxa more than doubled in size during the finishing period, differences in growth are less noticeable in visual observation. Due to its resilience in container production, this taxon may do well in peat-alternative substrates that can be marketed for their increased sustainability, similar to taxa investigated by Dede and Ozdemir (2014).

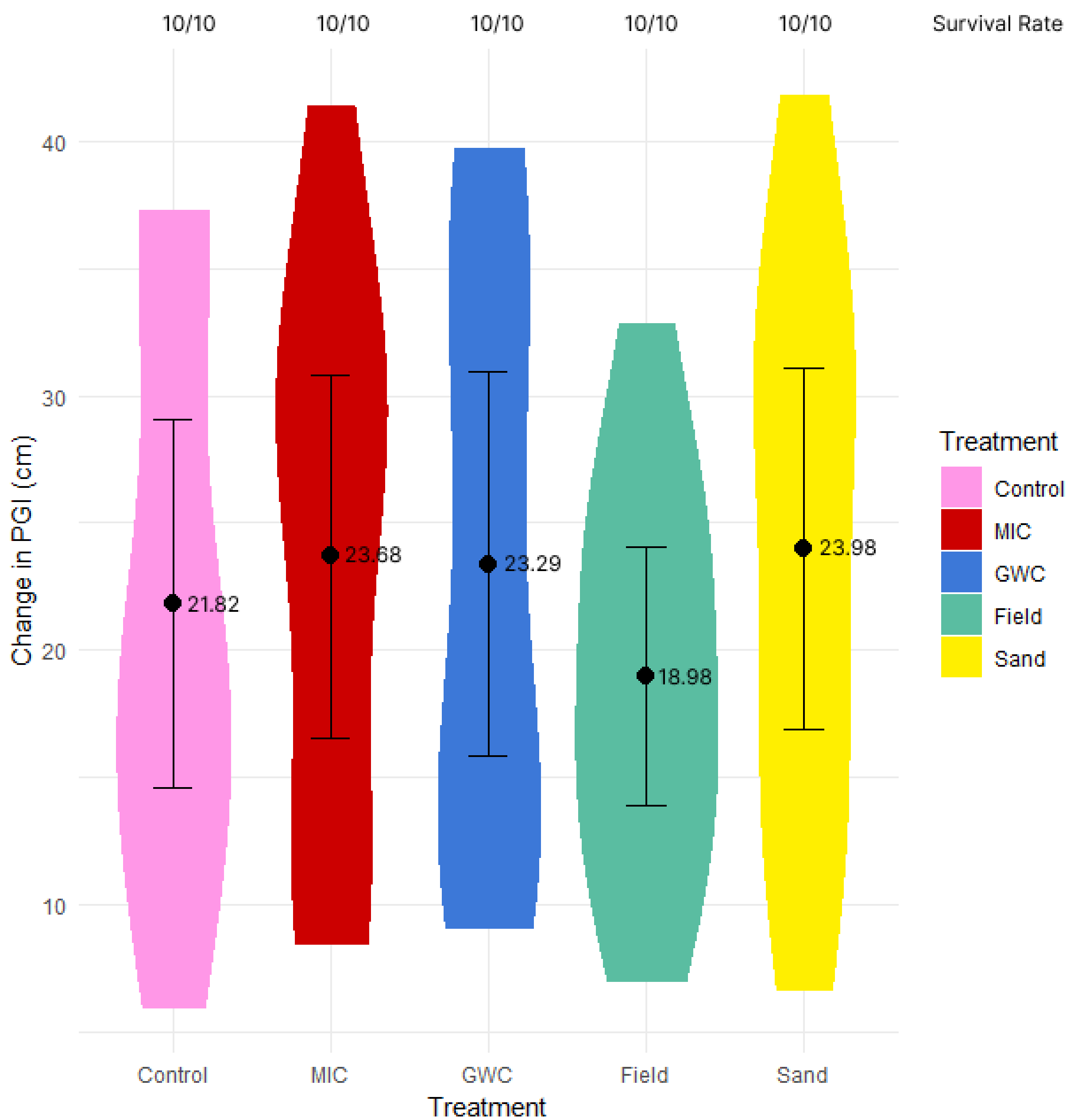

Figure 4. Change in plant growth index (PGI) over the 12 week finishing period in two growing seasons (2020, 2022) for *Andropogon gerardii* 'PWIN01S.' MIC = microbial-inoculated compost. GWC = green waste compost.

Though the field soil treatment had the smallest increase in growth, plants in the GWC treatment had a slightly lower, but similar, mean dry weight. The GWC treatment grew 4.41 cm larger than the field soil treatment on average, but the field soil treatment produced an equivalent, and more consistent, amount of above-ground biomass (Figure 5).

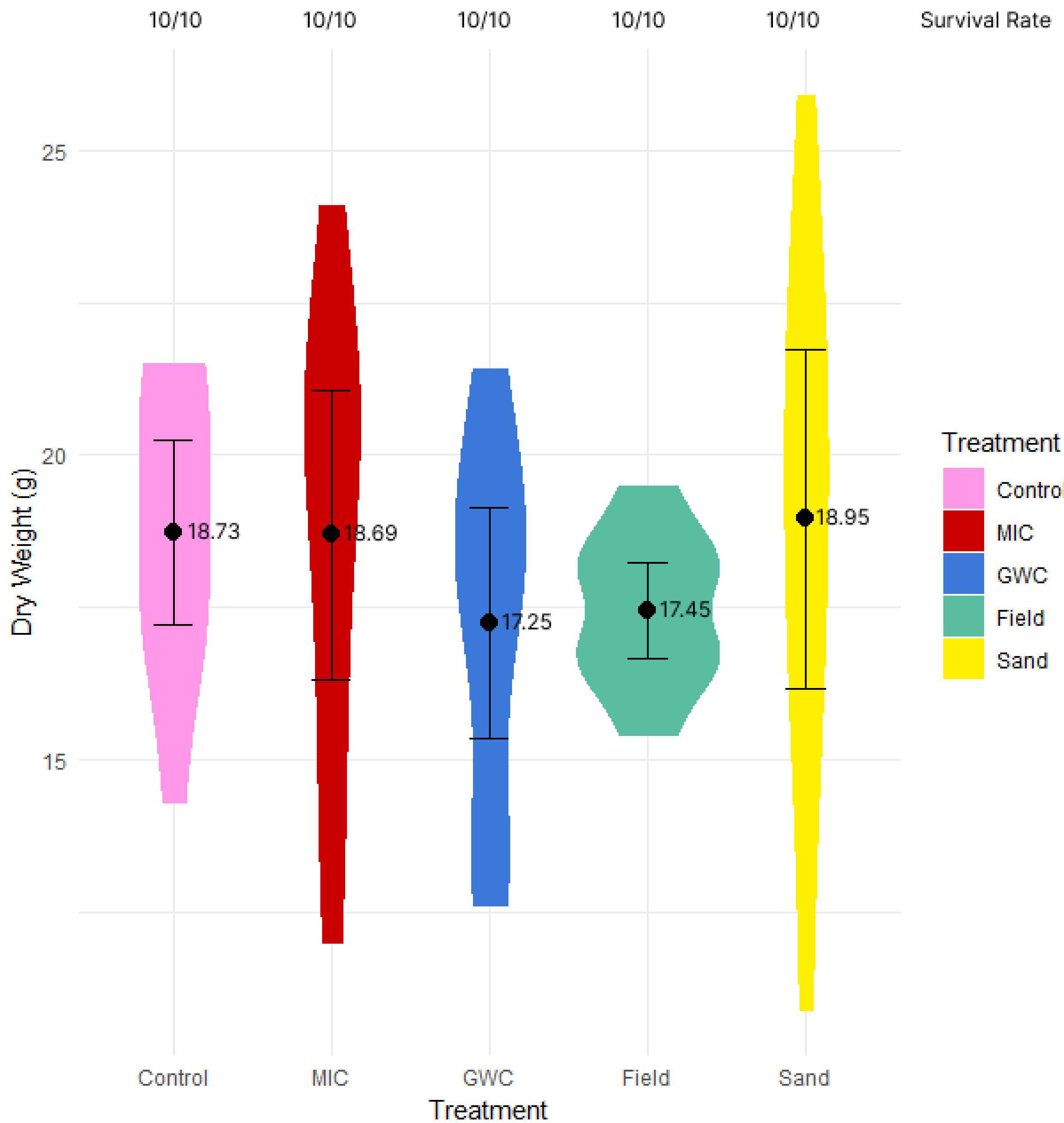

Figure 5. Above-ground dry weight after the 12-week finishing period in two growing seasons (2020, 2022) for *Andropogon gerardii* 'PWIN01S.' MIC = microbial-inoculated compost. GWC = green waste compost.

2.3.3 Growth Response and Survivability in *Eriogonum umbellatum* var. *aureum* 'Psdowns'

Eriogonum umbellatum var. *aureum* 'Psdowns' is a perennial forb with tomentose, mat-forming basal leaves (Ackerfield, 2022), which provide visual interest even when umbellate flowers are not present. In the landscape, this taxon can spread by seed and by stolons. This taxon can rot if overwatered and prefers good drainage in container cultivation. Survival rates were excellent among all treatments of *Eriogonum umbellatum* var. *aureum* ‘Psdowns,’ with only one replicate in the native soil treatment dying (Figure 6).

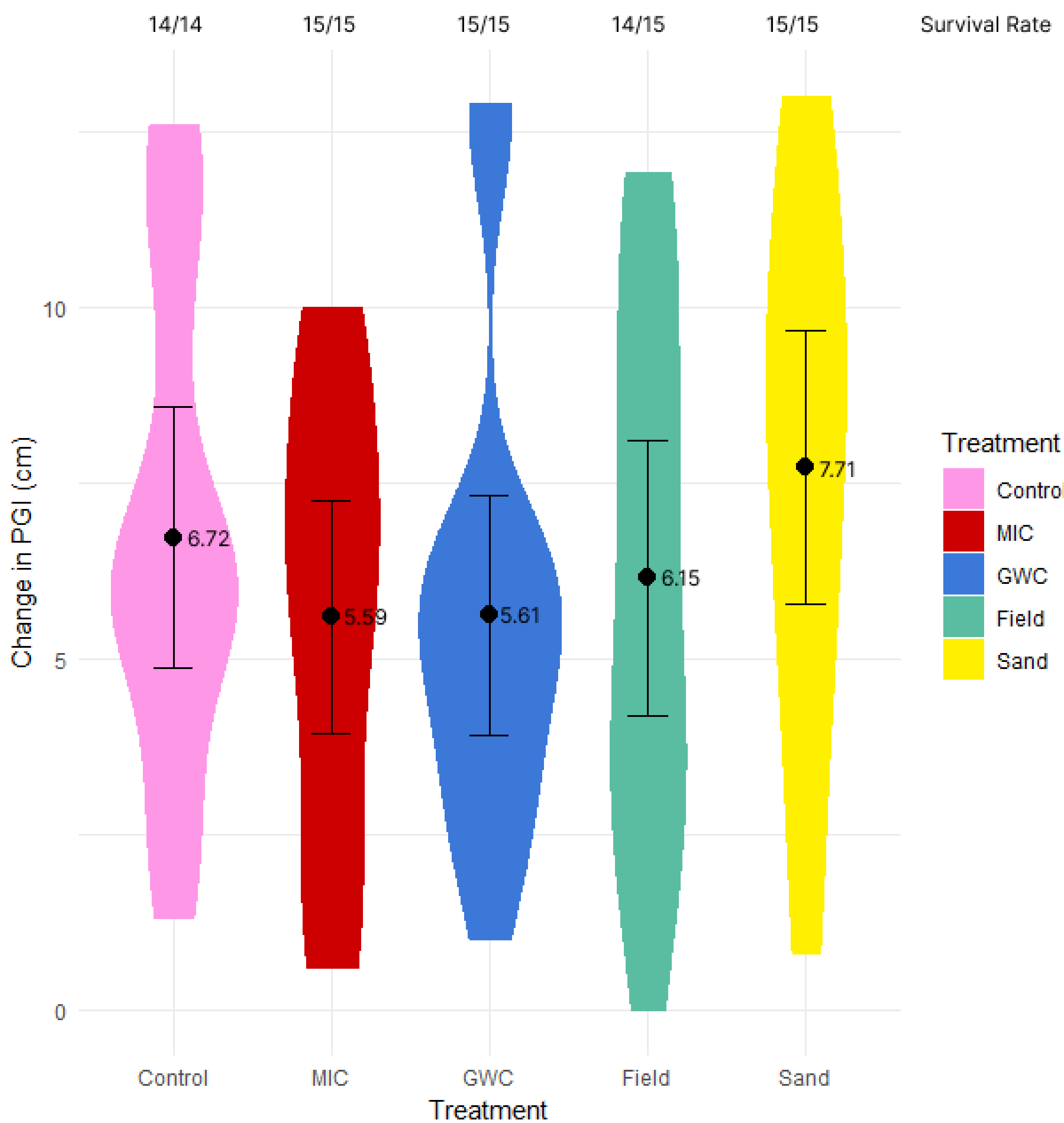

Figure 6. Change in plant growth index (PGI) over the 12 week finishing period in three growing seasons (2020, 2021, 2022) for *Eriogonum umbellatum* var. *aureum* ‘Psdowns.’ MIC = microbial-inoculated compost. GWC = green waste compost.

All treatments resulted in similar increases in PGI and adding either compost as an amendment did not result in any increase in growth during the finishing period. Plants in the sand treatment resulted in a significantly higher dry weight on average compared to the field soil treatment (Figure 7).

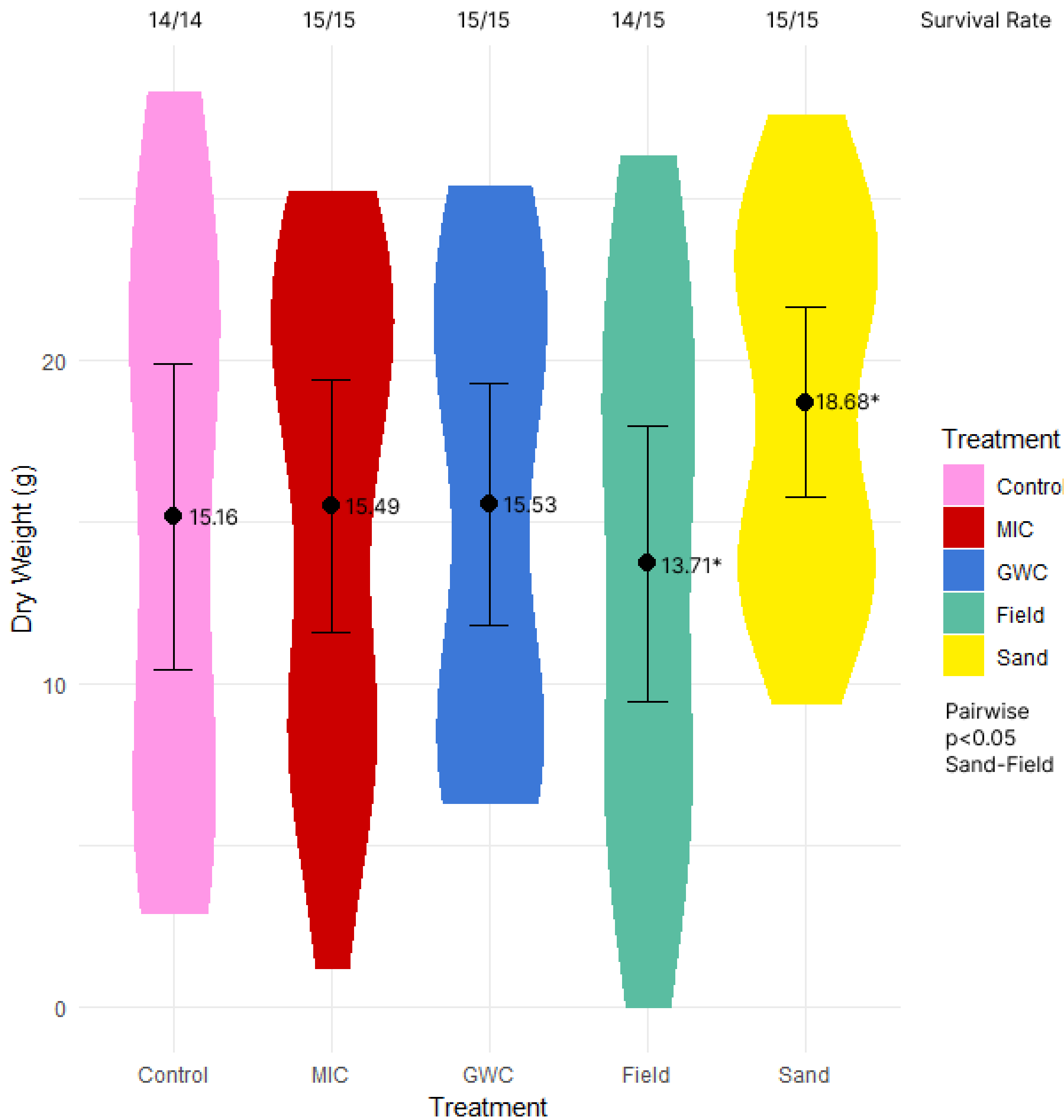

Figure 7. Above-ground dry weight after the 12-week finishing period in three growing seasons (2020, 2021, 2022) for *Eriogonum umbellatum* var. *aureum* 'Psdowns.' MIC = microbial-inoculated compost. GWC = green waste compost.

This stoloniferous taxon is adapted to low-nutrient, sandy soils where the plant can access water through modified stem tissue. Therefore, this *Eriogonum umbellatum var. aureum* ‘Psdowns’ performed well, as expected, in the sand treatment.

2.3.4 Growth Response and Survivability in *Geum triflorum*

Geum triflorum, a perennial forb, has pinnatifid basal leaves that have a tidy form. Flowers emerge on erect stalks and often have a nodding habit. These flowers become seed heads that appear as feathery plumes. This plant is often selected for the landscape setting due to the visual interest of the seed heads. Seeds are wind dispersed, and this plant can also spread through stout rhizomes that extend short distances (Munger 2006).

Survivability was excellent among all treatments of *Geum triflorum*, with only one replicate dying in the field soil treatment. There was little variability in PGI increase among treatments for this taxon. Replicates in the field soil treatment only grew 1.73 cm on average, less than doubling over the finishing period. On the upper end of the range, the control and MIC treatment increased 4.13 and 4.15 cm, respectively (Figure 8). Due to the relative uniformity of this taxon, small differences in growth are more likely to be visually apparent.

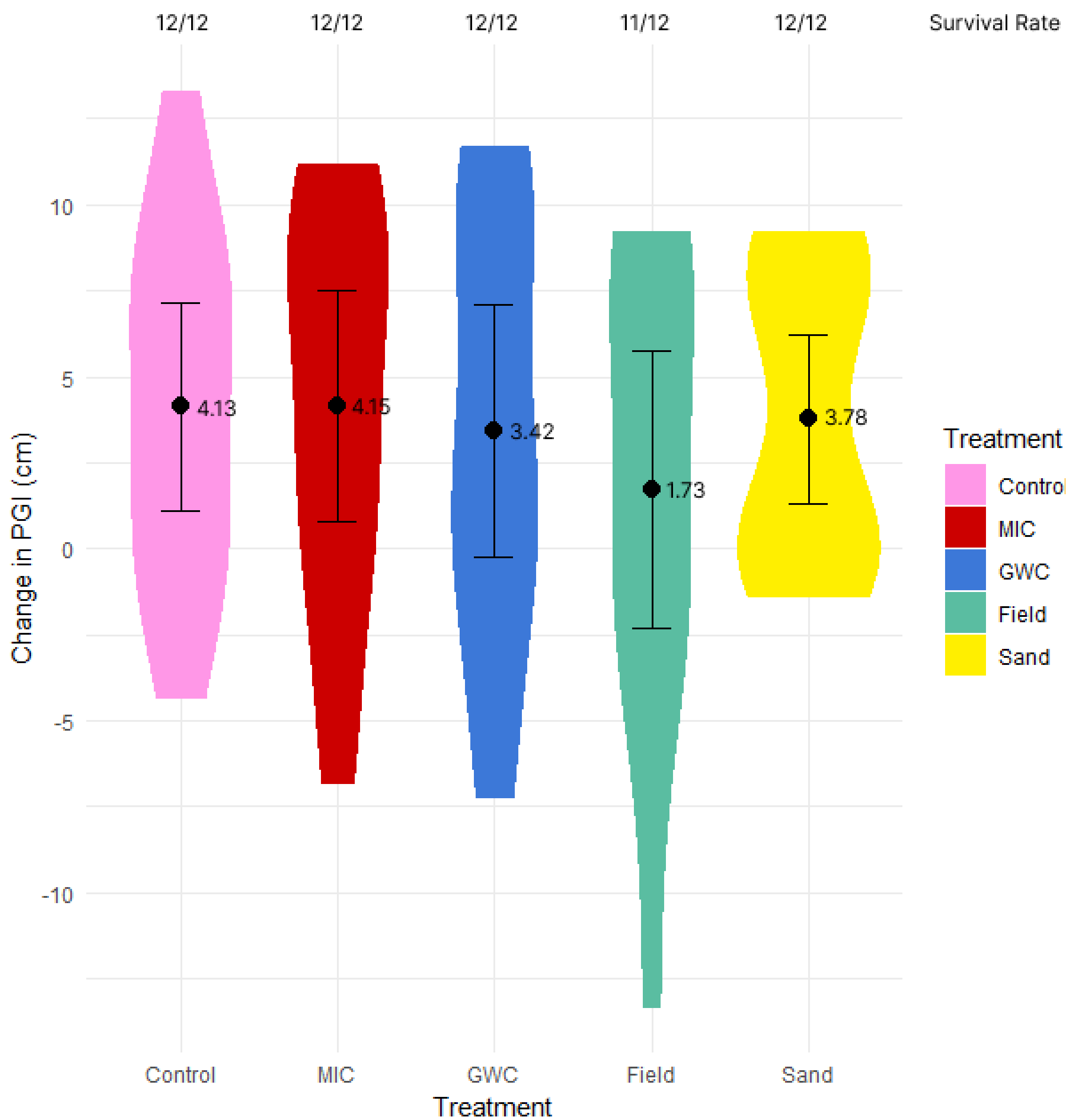

Figure 8. Change in plant growth index (PGI) over the 12 week finishing period in three growing seasons (2020, 2021, 2022) for *Geum triflorum*. MIC = microbial-inoculated compost. GWC = green waste compost.

The dry weights of the harvested above-ground biomass resulted in no significant differences between treatments, with only the field soil treatment having a slightly lower dry weight (Figure 9). *Geum triflorum* appears to tolerate peat-alternative substrates, though caution should be used when considering substrates that may lower drainage capacity.

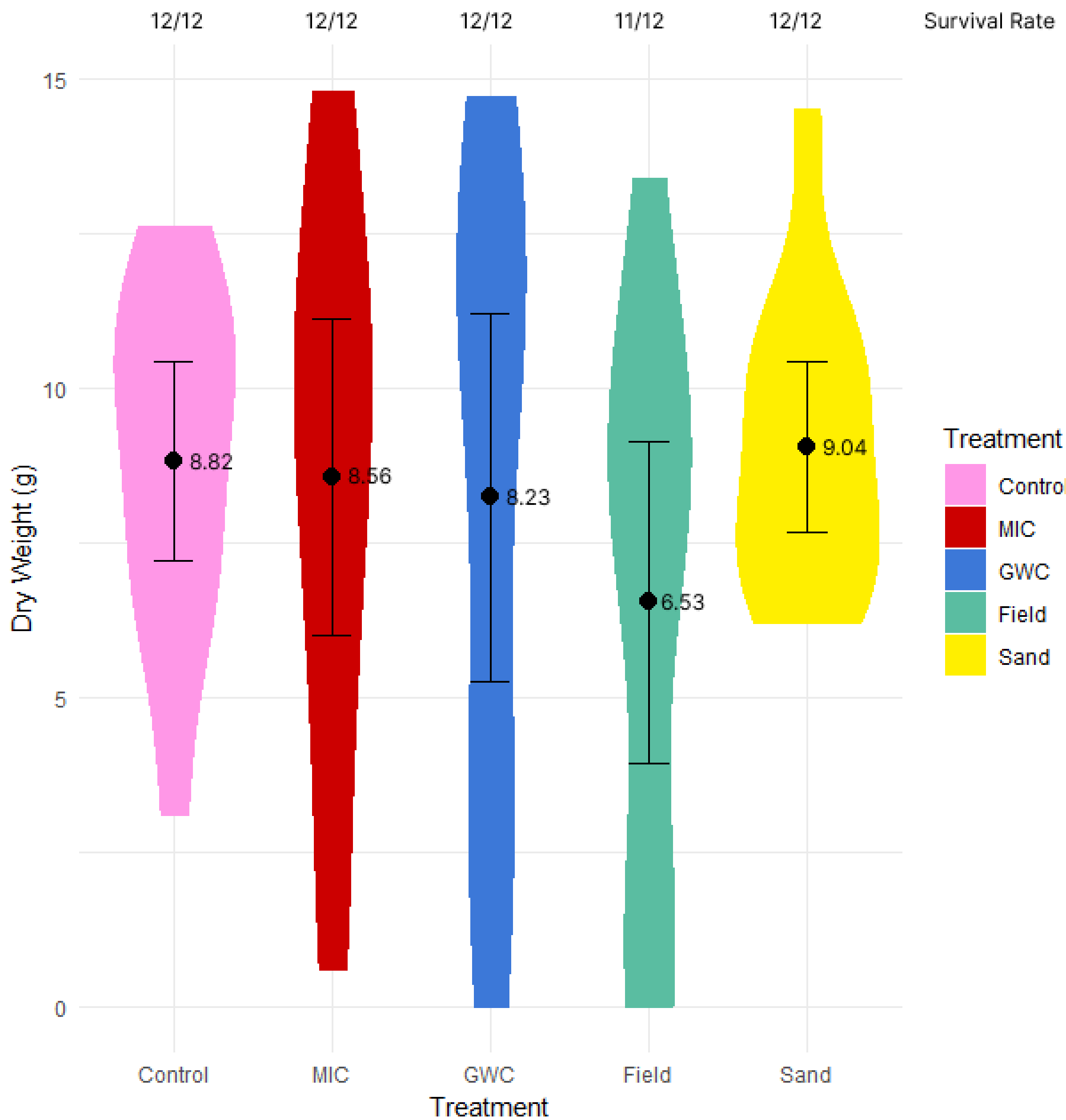

Figure 9. Above-ground dry weight after the 12-week finishing period in three growing seasons (2020, 2021, 2022) for *Geum triflorum*. MIC = microbial-inoculated compost. GWC = green waste compost.

2.3.5 Growth Response and Survivability in *Glandularia bipinnatifida*

Glandularia bipinnatifida can appear as a ground cover due to its prostrate growing habit (Ackerfield, 2022). This perennial forb produces numerous, long-lived clusters of purple flowers.

Growers tend to propagate this taxon vegetatively by rooting tip cuttings. In the landscape setting, this taxon is tolerant of many soil types and can flower from May to October.

The field soil treatment, as well as the control, had the lowest survivability and the smallest increases in PGI for *Glandularia bipinnatifida*. Only 12 of 15 replicates, or 80%, survived the finishing period in these groups. In the sand treatment only 13 of 15 replicates died. Only one replicate died in the MIC treatment and 100% of the replicates survived in the GWC treatment. Adding compost could potentially improve survivability of *Glandularia bipinnatifida* during the finishing period. The GWC and sand treatments showed the greatest increase in PGI over the finishing period, with an increase of 9.87 cm and 8.93 cm respectively (Figure 10).

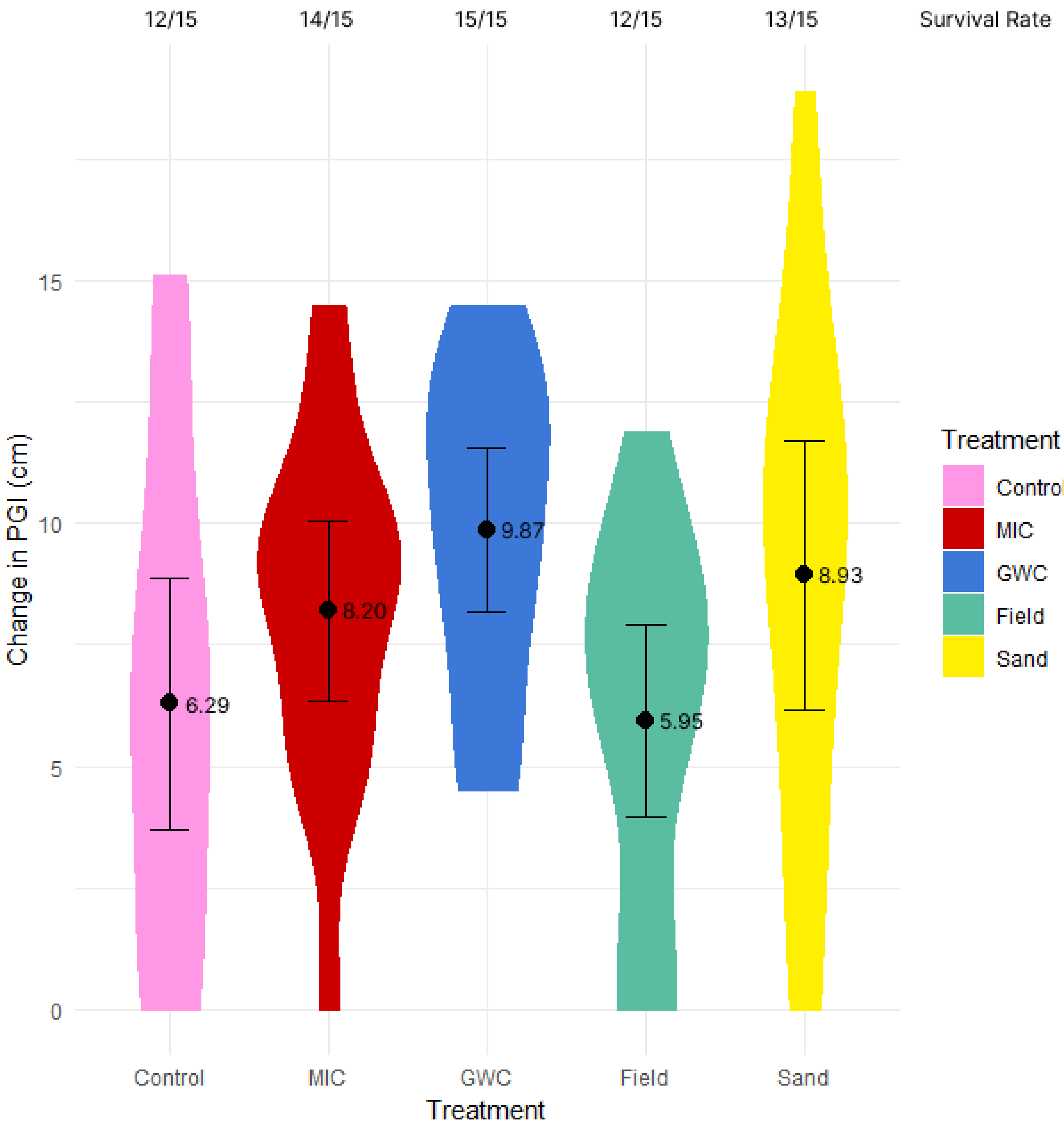

Figure 10. Change in plant growth index (PGI) over the 12 week finishing period in three growing seasons (2020, 2021, 2022) for *Glandularia bipinnatifida*. MIC = microbial-inoculated compost. GWC = green waste compost.

Dry weights of above-ground biomass resulted in no significant differences between treatments for *Glandularia bipinnatifida*. The MIC and GWC treatments had slightly higher dry weights compared to the other treatments (Figure 11).

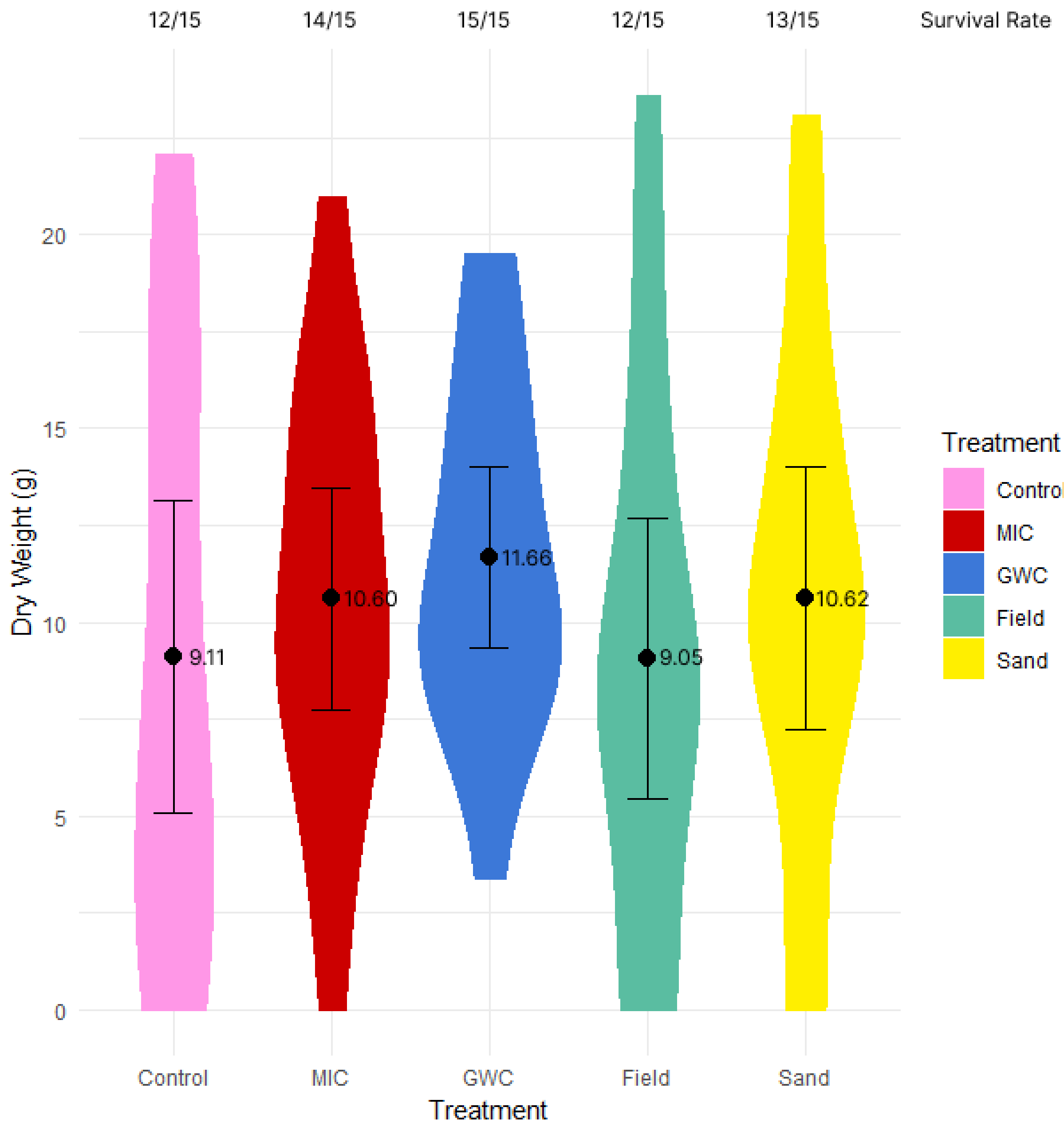

Figure 11. Above-ground dry weight after the 12-week finishing period in three growing seasons (2020, 2021, 2022) for *Glandularia bipinnatifida*. MIC = microbial-inoculated compost. GWC = green waste compost.

2.3.6 Growth Response and Survivability in *Liatris ligulistylis*

Liatris ligulistylis is a towering perennial forb that can grow up to 1 m tall. Purple disk flowers emerge along the stems and provide late season color and nectar resources. In its natural habitat this taxon is found in moist areas and along streams. It is often planted in landscape settings for the visual interest that its tall flower spikes provide and to attract pollinators who enjoy its nectar.

Survival rates for *Liatris ligulistylis* were lowest in the control and sand groups and only 11 of 15 replicates survived the finishing period. Survival rates were 100% in the MIC and GWC groups (Figure 12). Adding compost could facilitate better survival rates in containers for this taxon, which is prone to drying out in the final weeks of the finishing period.

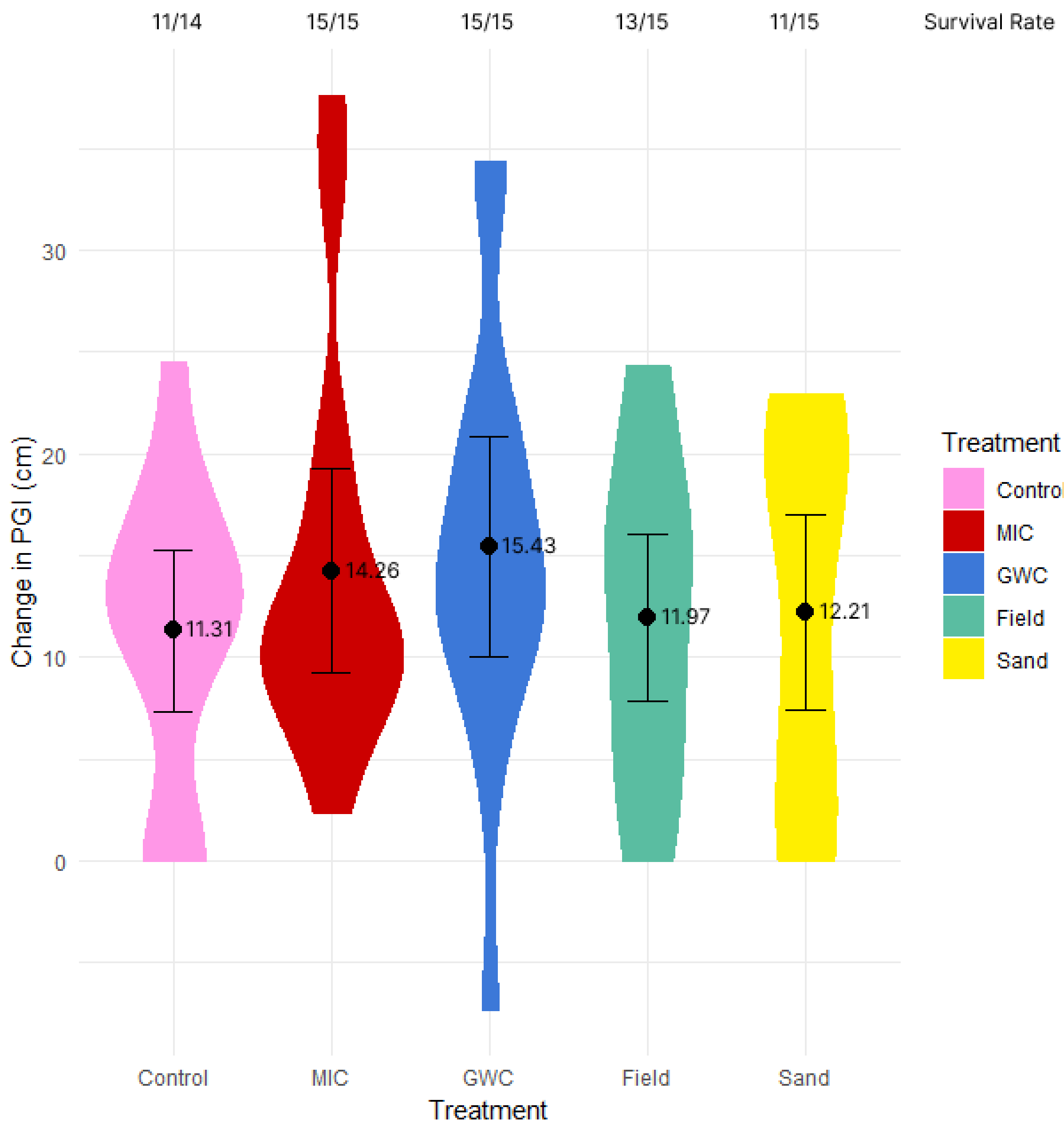

Figure 12. Change in plant growth index (PGI) over the 12 week finishing period in three growing seasons (2020, 2021, 2022) for *Liatris ligulistylis*. MIC = microbial-inoculated compost. GWC = green waste compost.

Increase in PGI over the finishing period for *Liatris ligulistylis* was similar for the control, native, and sand treatments. The MIC and GWC treatments showed a slightly higher increase in growth. However, there was more variability within these treatments with a few individuals showing a very high increase in PGI.

Of the two compost treatments, the MIC treatment resulted in a higher dry weight than the GWC treatment, though this was not statistically significant. The GWC treatment had a dry weight similar to the other treatments (Figure 13). Adding an amendment in the form of a compost inoculated with beneficial microbes could facilitate greater above-ground biomass during the finishing period for *Liatris ligulistylis*.

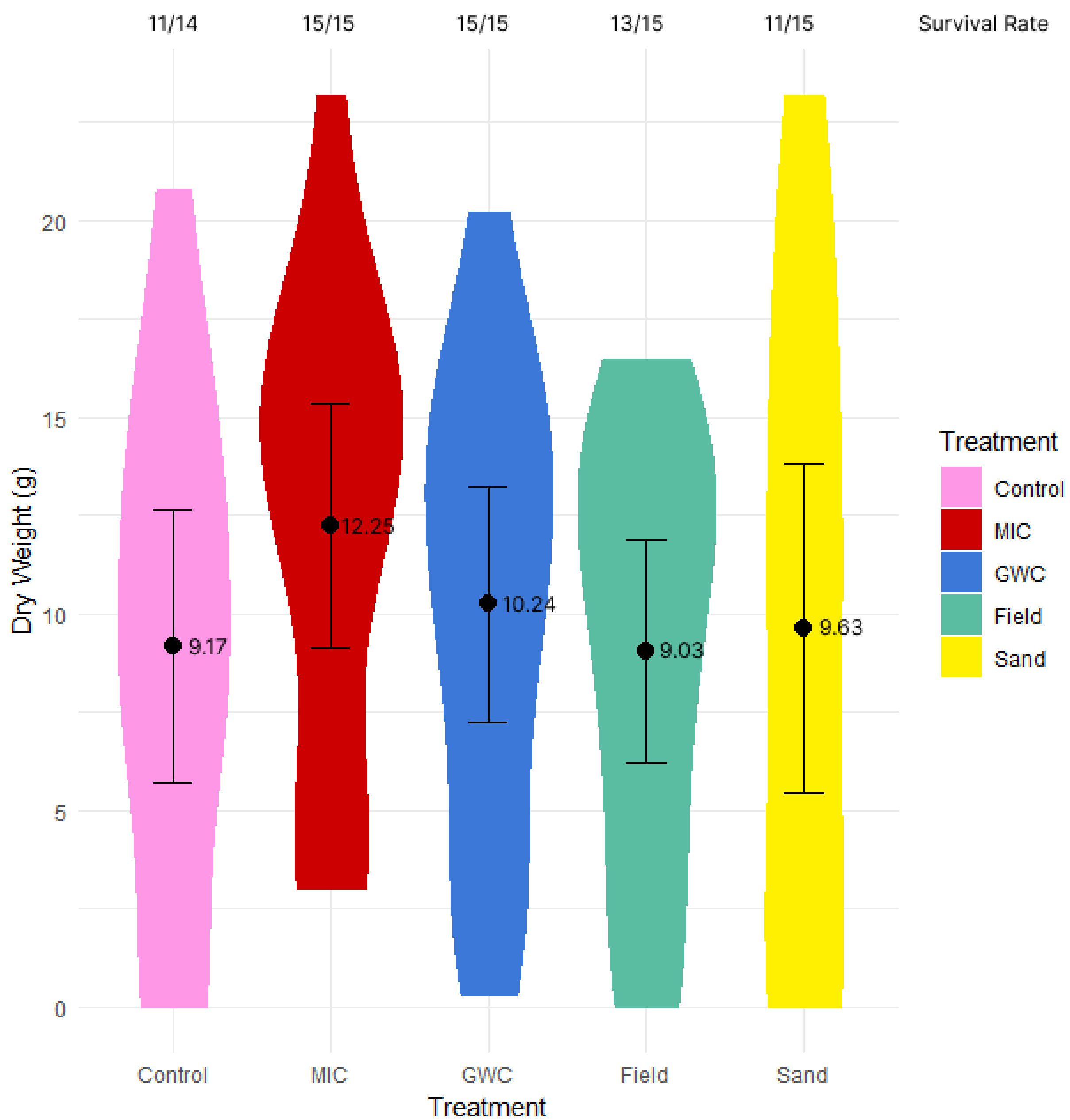

Figure 13. Above-ground dry weight after the 12-week finishing period in three growing seasons (2020, 2021, 2022) for *Liatris ligulistylis*. MIC = microbial-inoculated compost. GWC = green waste compost.

2.3.7 Growth Response and Survivability in *Mirabilis multiflora*

Mirabilis multiflora is a low-growing perennial forb that tolerates poor soils and dry sites. It is propagated from seed, cuttings, or by dividing the tuberous roots. Up to six flowers may emerge per head (Ackerfield, 2022), and the magenta blooms open in the evening and remain open throughout the night and into the cool morning hours before tightly closing (Carter et al., 2018). Even when flowers are not present, thick, silvery, oval-shaped leaves form a vegetative mat, providing interest in the landscape.

Mirabilis multiflora showed a slightly increased change in PGI in the GWC treatment, but interestingly did not respond in the same way to the MIC treatment (Figure 14). The sand treatment also showed slightly increased change in PGI compared to the control, field soil, and MIC treatments. All of the treatments showed relatively similar increases in growth, given that this taxon more than tripled in PGI throughout the finishing period. Due to this large increase in growth and the mat-forming growing habit, small differences in PGI may not be visually noticeable.

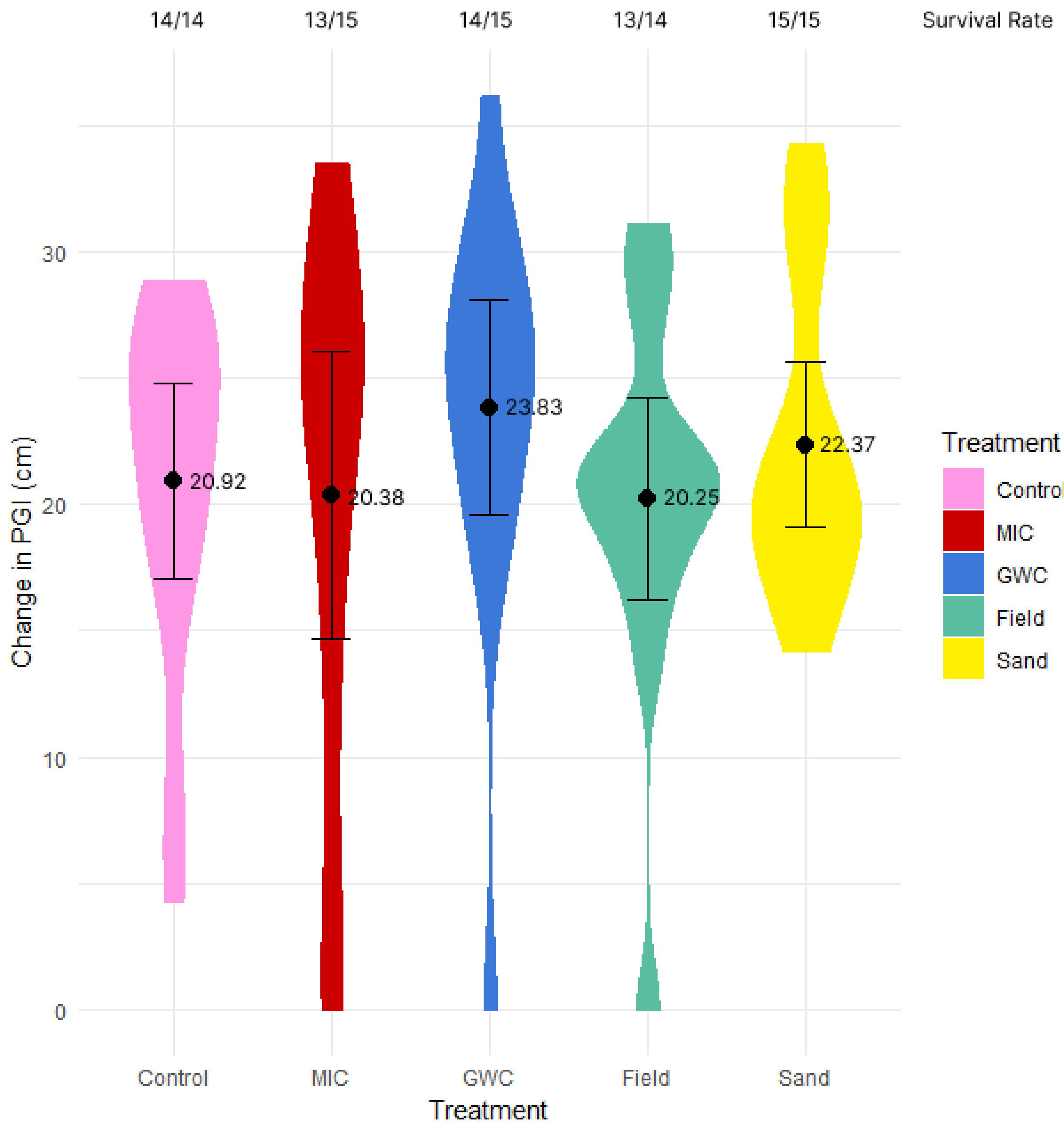

Figure 14. Change in plant growth index (PGI) over the 12 week finishing period in three growing seasons (2020, 2021, 2022) for *Mirabilis multiflora*. MIC = microbial-inoculated compost. GWC = green waste compost.

Dry weights were similar across treatments for *Mirabilis multiflora*, with the sand treatment resulting in a slightly greater biomass than the other treatments and the native treatment resulting in a slightly lower biomass (Figure 15). *Mirabilis multiflora* appears to be tolerant of peat-reduced substrates in container production.

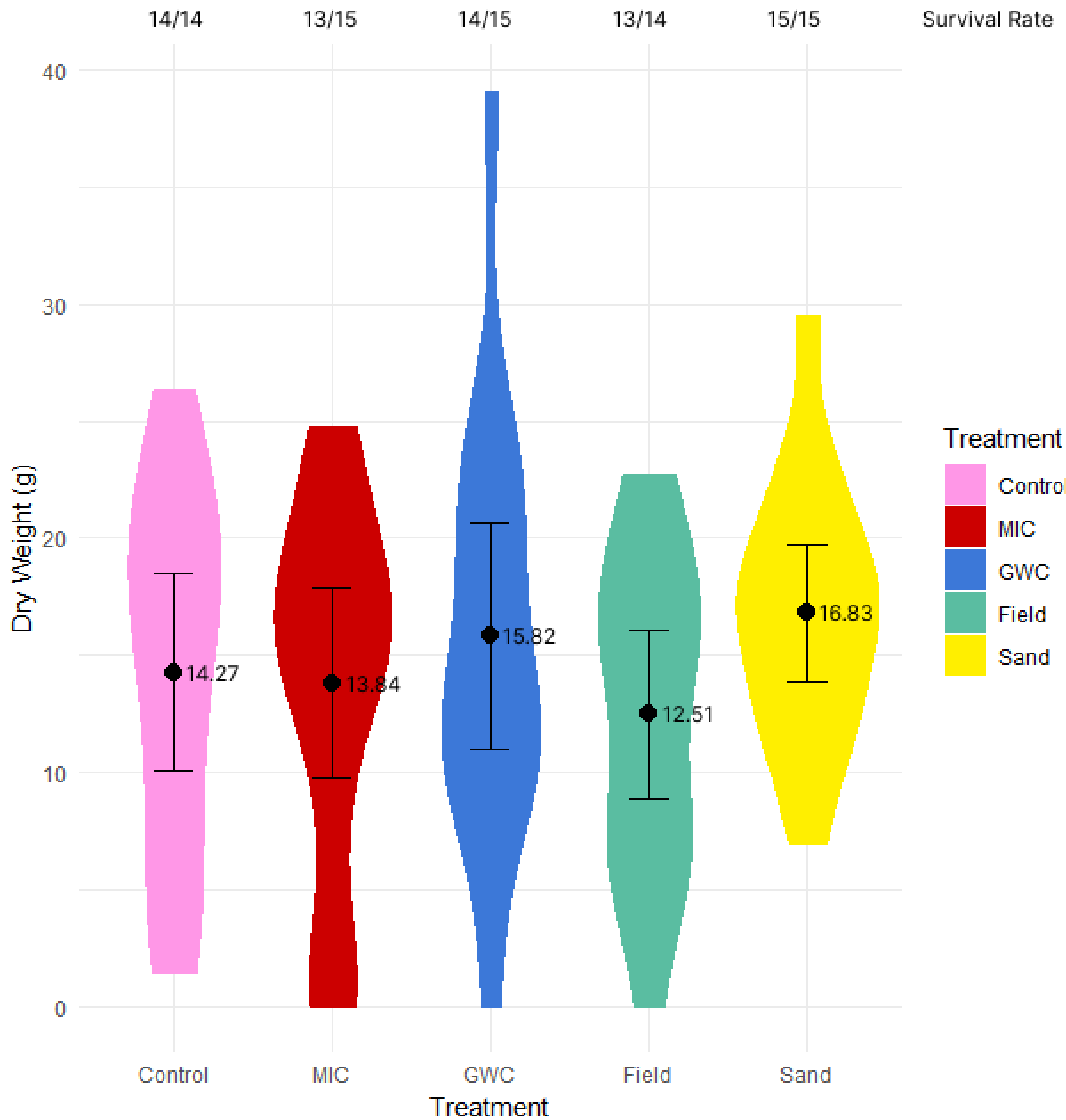

Figure 15. Above-ground dry weight after the 12-week finishing period in three growing seasons (2020, 2021, 2022) for *Mirabilis multiflora*. MIC = microbial-inoculated compost. GWC = green waste compost.

2.3.8 Growth Response and Survivability in *Penstemon linarioides* ssp. *coloradoensis* ‘P014S’

Penstemon linarioides ssp. *coloradoensis* ‘P014S’ is a selection of the native taxon, and thus, is propagated from stem cuttings. Silvery, blue-green linear leaves remain green year-round and small blue-purple flowers provide an early nectar source in May and June. This compact taxon is often selected because it provides an interesting texture in the landscape.

Greatest survivability was observed in the MIC treatment for *Penstemon linarioides* ssp. *coloradoensis* ‘P014S’ and this was the only treatment to result in a 100% survival rate. Replicates in the field soil group had the lowest survival rate with only 7 of 10 replicates surviving the finishing period. The field soil treatment also resulted in a lower increase in PGI over the finishing period (Figure 16). PGI more than doubled in the MIC, control, and sand treatment, while the native treatment resulted in only a 70% increase in PGI over the finishing period. These differences among treatments were visually apparent, and a few replicates in all treatments, other than the MIC treatment, showed symptoms of a root rot pathogen in 2022.

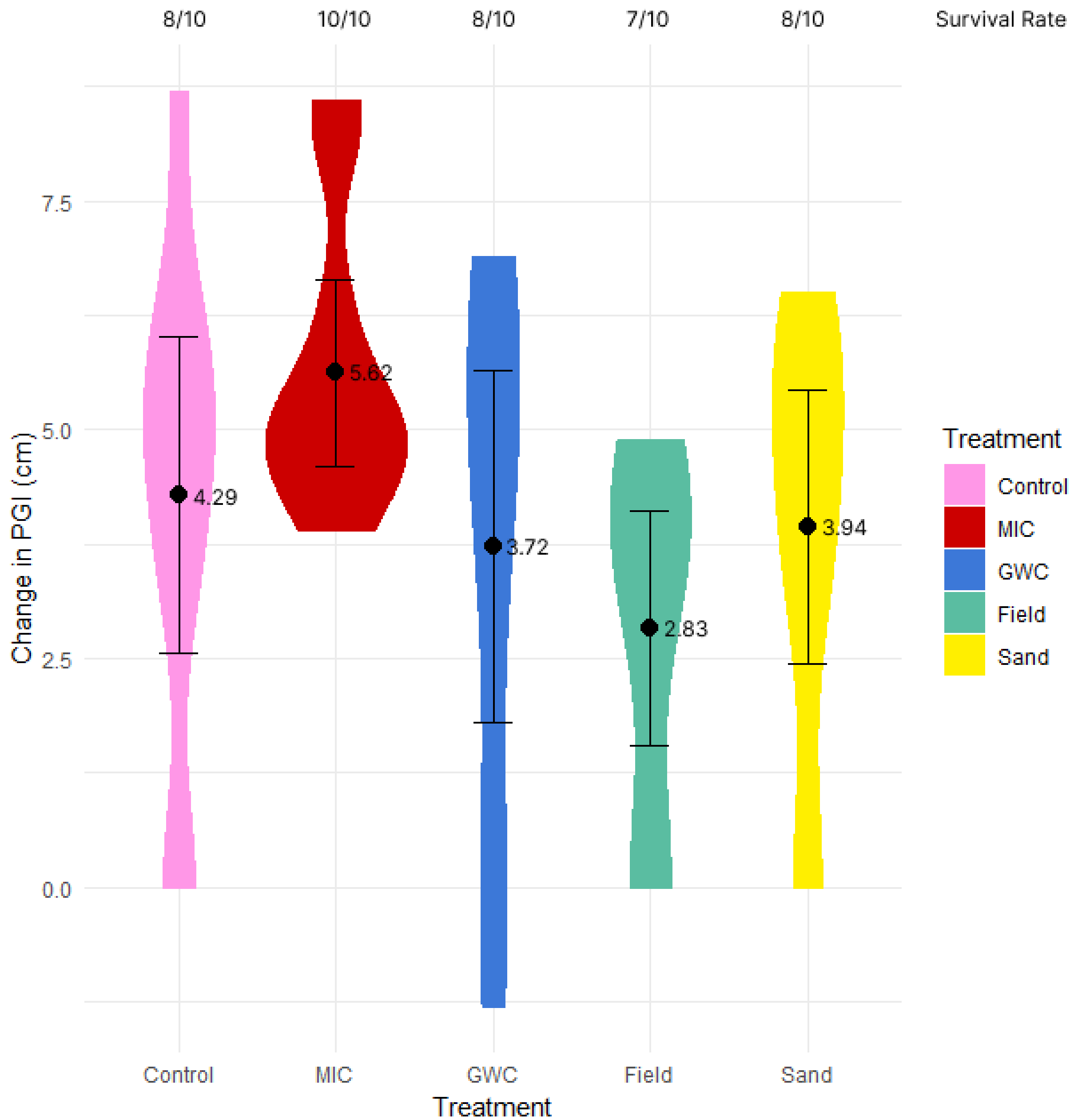

Figure 16. Change in plant growth index (PGI) over the 12 week finishing period in two growing seasons (2021, 2022) for *Penstemon linarioides* ssp. *coloradoensis* ‘P014S.’ MIC = microbial-inoculated compost. GWC = green waste compost.

Dry weights of replicates in the MIC treatment were significantly higher than that of replicates in the field soil treatment (Figure 17). Dry weights in the MIC treatment showed good uniformity and replacing peat with a compost inoculated with beneficial microbes could result in increased above-ground biomass for *Penstemon linarioides* ssp. *coloradoensis* ‘P014S.’ This taxon often does not flower in containers during the finishing period, so excellent above-ground vegetative growth is required for marketability of this compact plant.

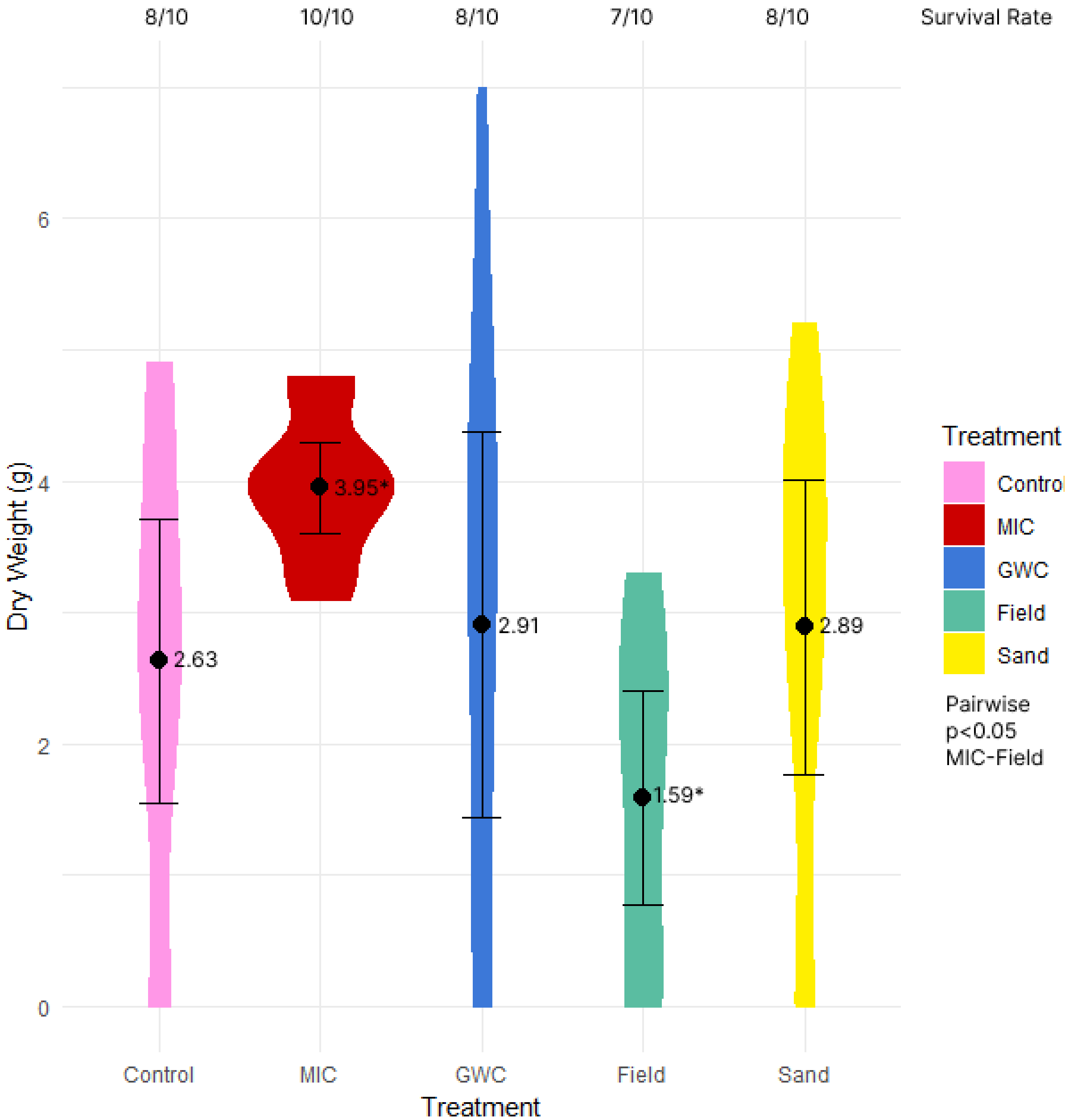

Figure 17. Above-ground dry weight after the 12-week finishing period in two growing seasons (2021, 2022) for *Penstemon linarioides* ssp. *coloradoensis* ‘P014S.’ MIC = microbial-inoculated compost. GWC = green waste compost.

2.3.9 Growth Response and Survivability in *Penstemon pinifolius* ‘P019S’

Penstemon pinifolius ‘P019S’ is a selection of an evergreen perennial forb known for its brilliant orange flowers. Its native range is south of Colorado in New Mexico and Arizona. This selection, propagated from cuttings, is relatively compact and tidy and attracts hummingbirds and pollinators into the mid-season and sometimes later.

Penstemon species are known to be impacted by root rot pathogens including *Rhizoctonia* spp., *Phyophthora* spp., and *Fusarium* spp. in cultivation (Scheidt and Ocamb, 2023). *Penstemon pinifolius* ‘P019S’ was susceptible to disease pressures in this study, and replicates across all treatments died. Testing in 2022 showed the presence of *Fusarium acuminatum*, a fungal pathogen that can lead to root rot symptoms and dieback.

Replicates in the MIC treatment showed the best survival rates with 13 of 15 replicates surviving (Figure 18). This may indicate potential for actinobacteria to aid in plant stress response to *Fusarium* species. Replicates in the control group showed the lowest survival rates with 7 of 15 replicates surviving and had a significantly lower PGI change. Based on this analysis, an unamended peat-based growing media would not be advised for *Penstemon pinifolius* ‘P019S’.

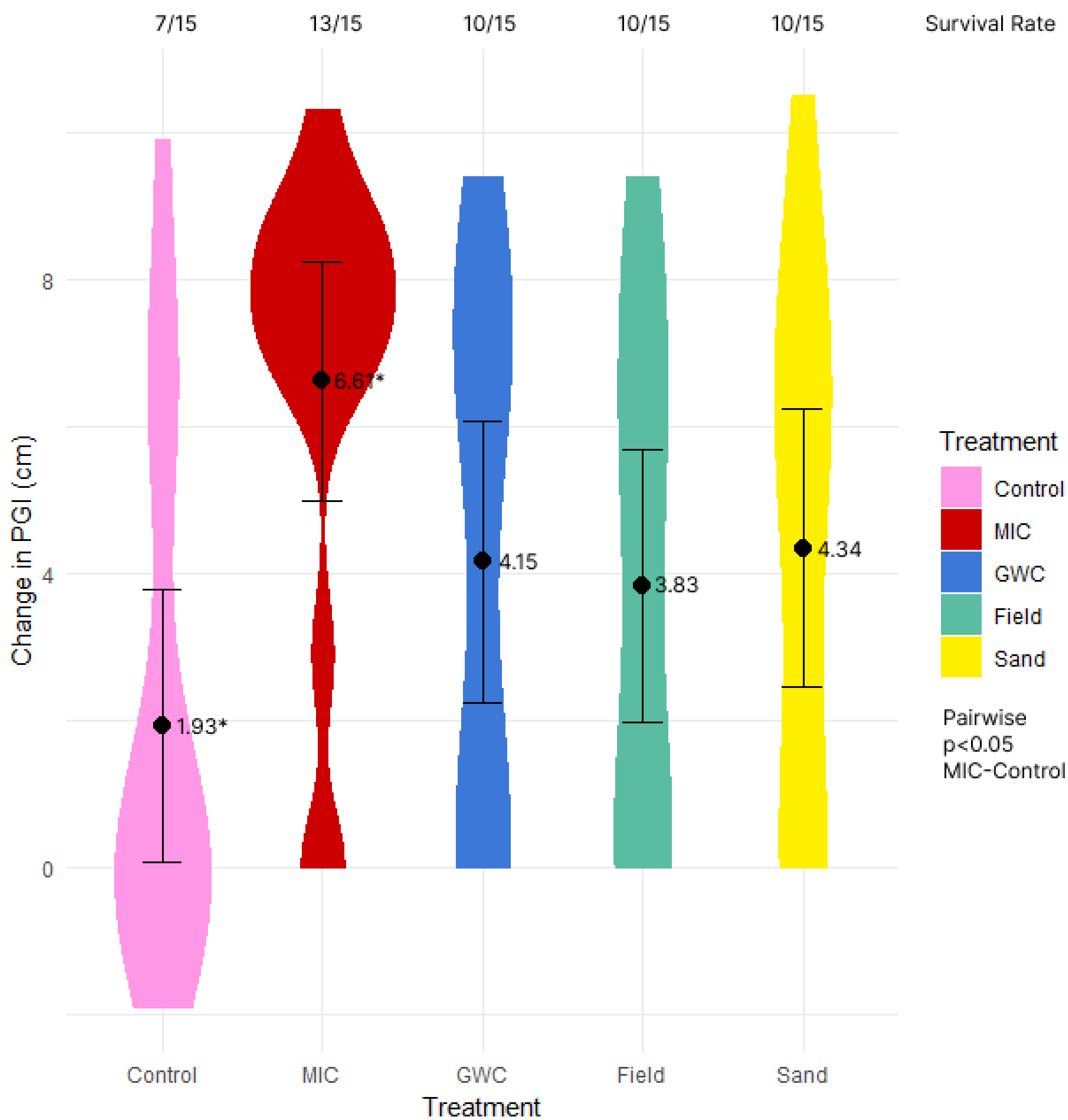

Figure 18. Change in plant growth index (PGI) over the 12 week finishing period in three growing seasons (2020, 2021, 2022) for *Penstemon pinifolius* 'P019S.' MIC = microbial-inoculated compost. GWC = green waste compost.

Replicates in the MIC treatment showed the highest increase in PGI for *Penstemon pinifolius* 'P019S' over the finishing period, and this was significantly greater than replicates in the control group. This taxon less than doubled in PGI over the finishing period, and thus, small differences in PGI were visually apparent.

Dry weights of replicates in the MIC treatment were also significantly greater than dry weights observed in the control and field soil treatments for *Penstemon pinifolius* ‘P019S’ (Figure 19). Since this late-flowering taxon may not be exhibiting phenological characteristics in the container during the finishing period, it is critical that above-ground biomass is maximized for improved marketability in containers.

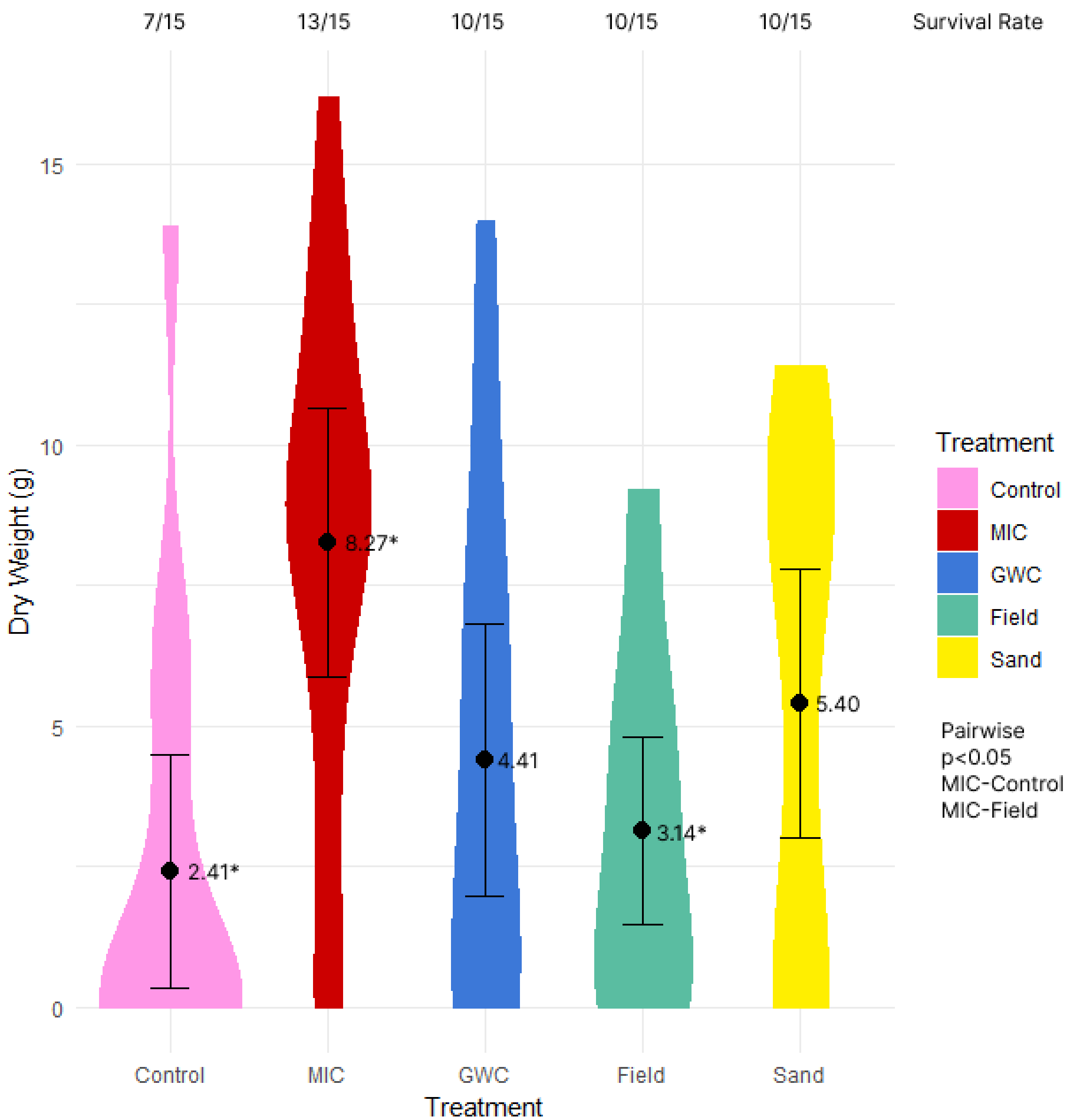

Figure 19. Above-ground dry weight after the 12-week finishing period in three growing seasons (2020, 2021, 2022) for *Penstemon pinifolius* 'P019S.' MIC = microbial-inoculated compost. GWC = green waste compost.

2.3.10 Growth Response and Survivability in *Penstemon pseudospectabilis*

Penstemon pseudospectabilis is native to areas surrounding Colorado including, New Mexico, Arizona, Utah, and California. This perennial forb has a more upright habit and features bright pink flowers that attract hummingbirds, among other pollinators. In the landscape setting, these blooms provide color that is not as common in other native taxon.

Greatest survivability of *Penstemon pseudospectabilis* was observed in the MIC treatment, with 100% survival (Figure 20). This was the only treatment resulting in 100% survival. The lowest survivability (70%) was observed in the sand treatment. This taxon showed relatively similar increases in PGI across treatments, though the MIC treatment resulted in slightly higher increases in PGI. The sand treatment had the lowest increase in PGI, but because this taxon more than doubled in PGI during the finishing period, these differences are less visually apparent.

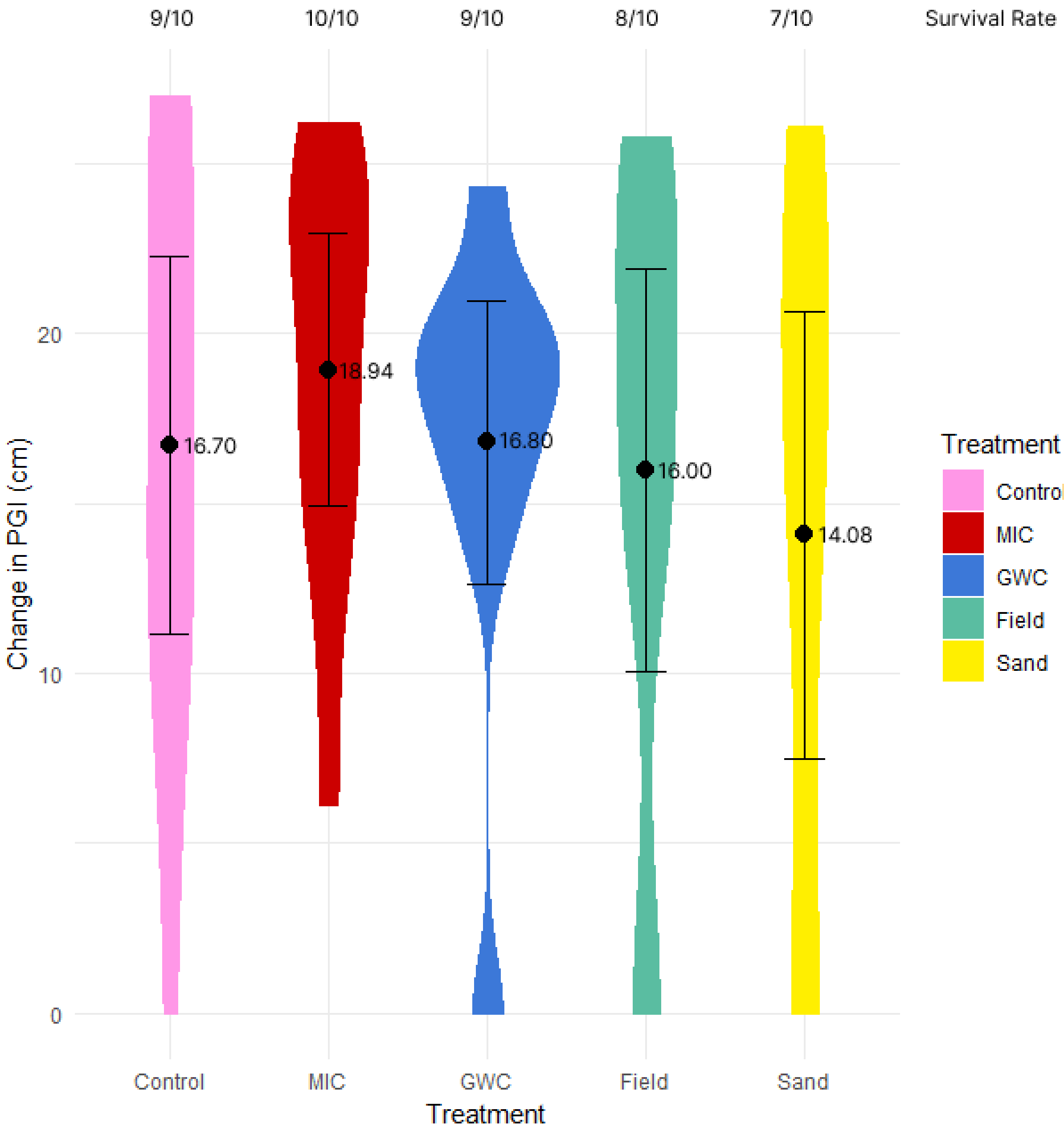

Figure 20. Change in plant growth index (PGI) over the 12 week finishing period in two growing seasons (2020, 2021) for *Penstemon pseudospectabilis*. MIC = microbial-inoculated compost. GWC = green waste compost.

Dry weights were somewhat similar across all treatments of *Penstemon pseudospectabilis* (Figure 21). Though the MIC treatment showed slightly higher increases in

PGI over the finishing period, the GWC treatment had slightly higher dry weights. The field soil treatment resulted in the lowest dry weights compared to other treatments.

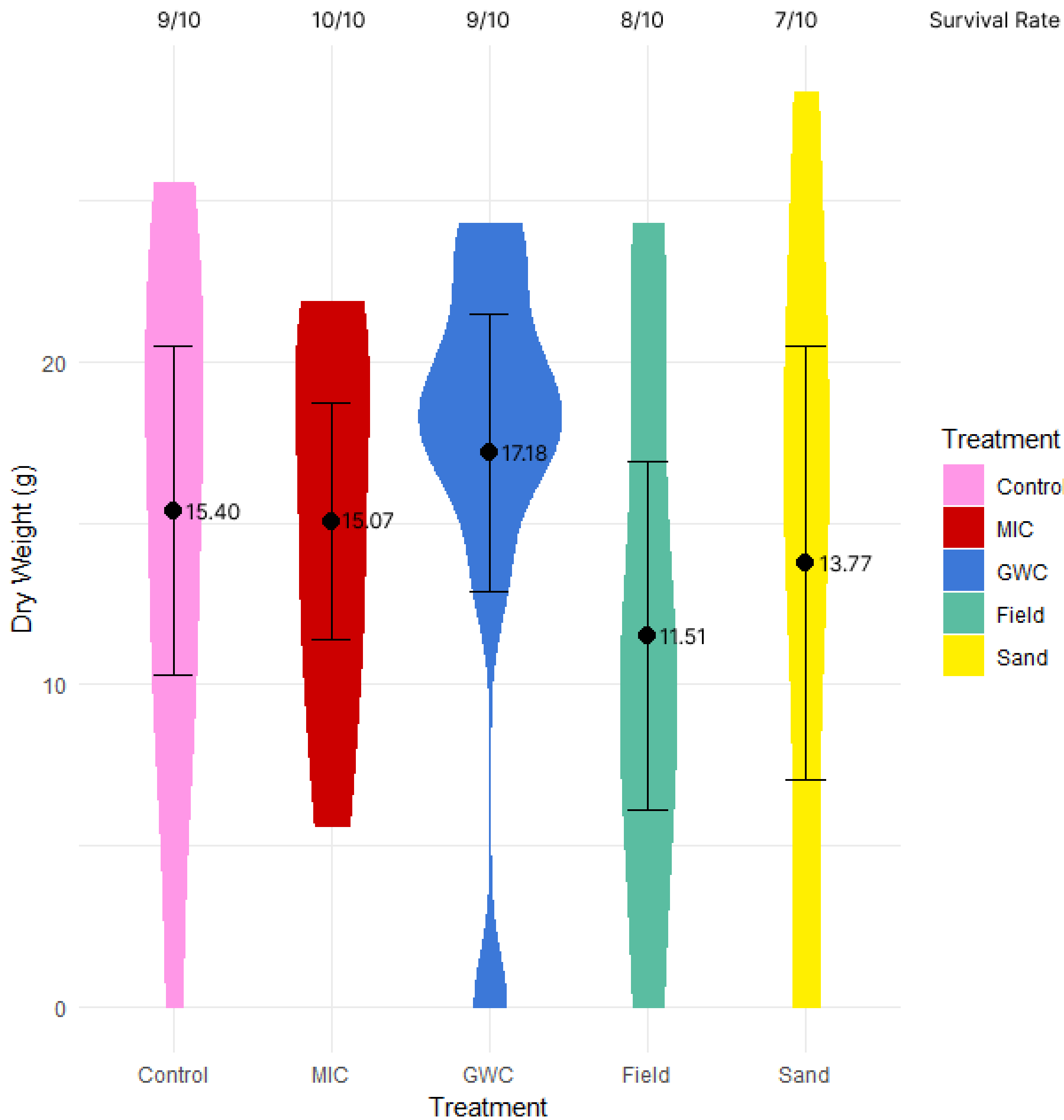

Figure 21. Above-ground dry weight after the 12-week finishing period in two growing seasons (2020, 2021) for *Penstemon pseudospectabilis*. MIC = microbial-inoculated compost. GWC = green waste compost.

2.3.11 Growth Response and Survivability in *Penstemon rostriflorus*

Penstemon rostriflorus is an upright perennial forb that has a tendency to sprawl a bit. It is profusely dotted with red flowers throughout the season and will even flower in containers during the finishing period. This taxon is reported to tolerate many soil types including soils in disturbed areas.

The greatest survivability of *Penstemon rostriflorus* was observed in the sand treatment, the only treatment with 100% survival (Figure 22). Only 11 of 15 replicates, or 73%, survived in the field soil treatment. The increase in PGI was relatively similar across the control, MIC, and GWC groups for this taxon, while the replicates in the field soil treatment had a somewhat lower increase in PGI. PGI more than tripled over the finishing period in the control, MIC, GWC, and sand treatments but only doubled in the field soil treatment. This difference may be visually noticeable.

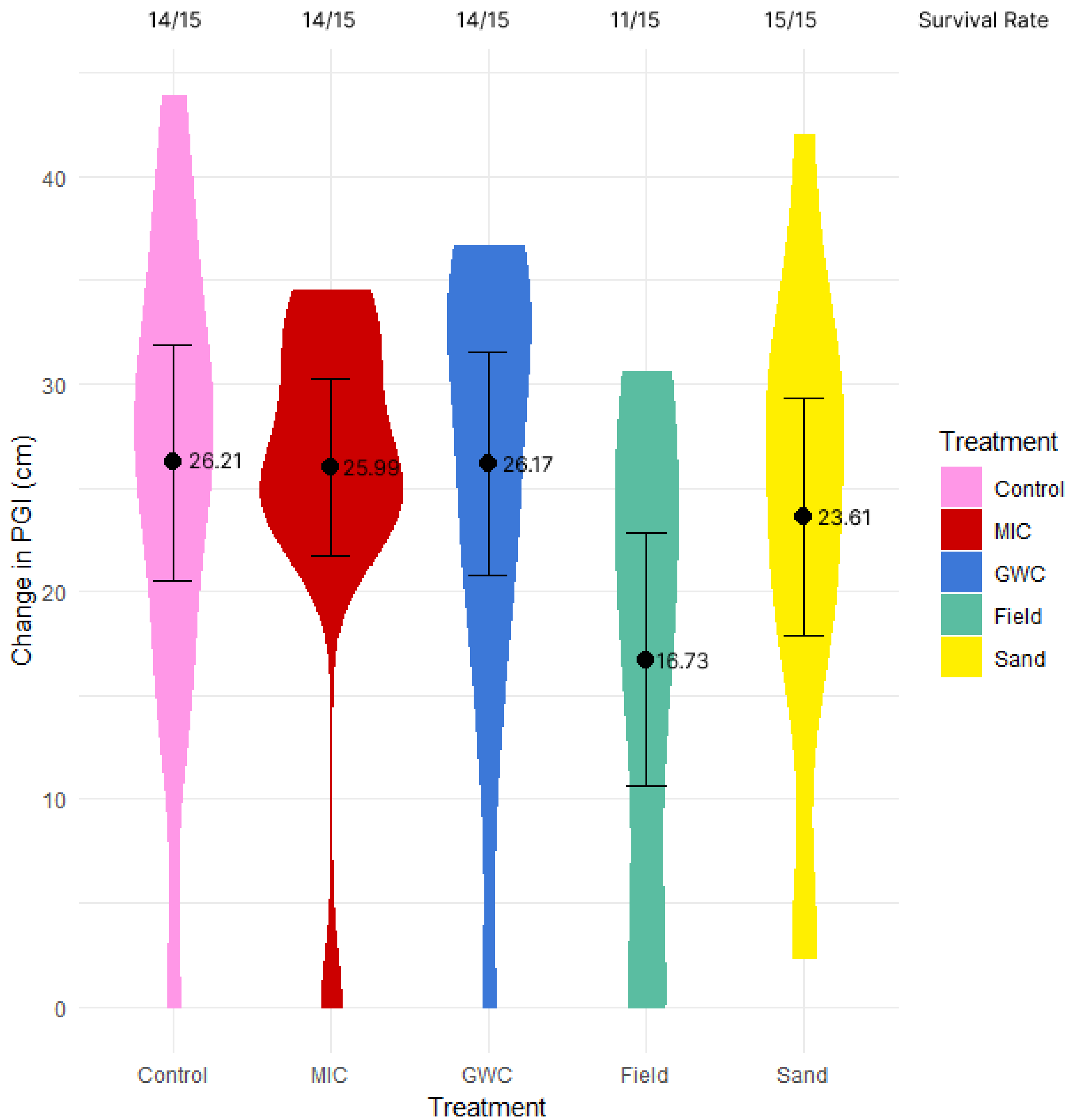

Figure 22. Change in plant growth index (PGI) over a 12 week finishing period in three growing seasons (2020, 2021, 2022) for *Penstemon rostriflorus*. MIC = microbial-inoculated compost. GWC = green waste compost.

The dry weight of *Penstemon rostriflorus* in the native soil treatment was significantly lower than the MIC treatment (Figure 23). While flowers and buds may be present on this taxon during the finishing period in containers, it is still important that above-ground biomass is not compromised by the substrate selection.

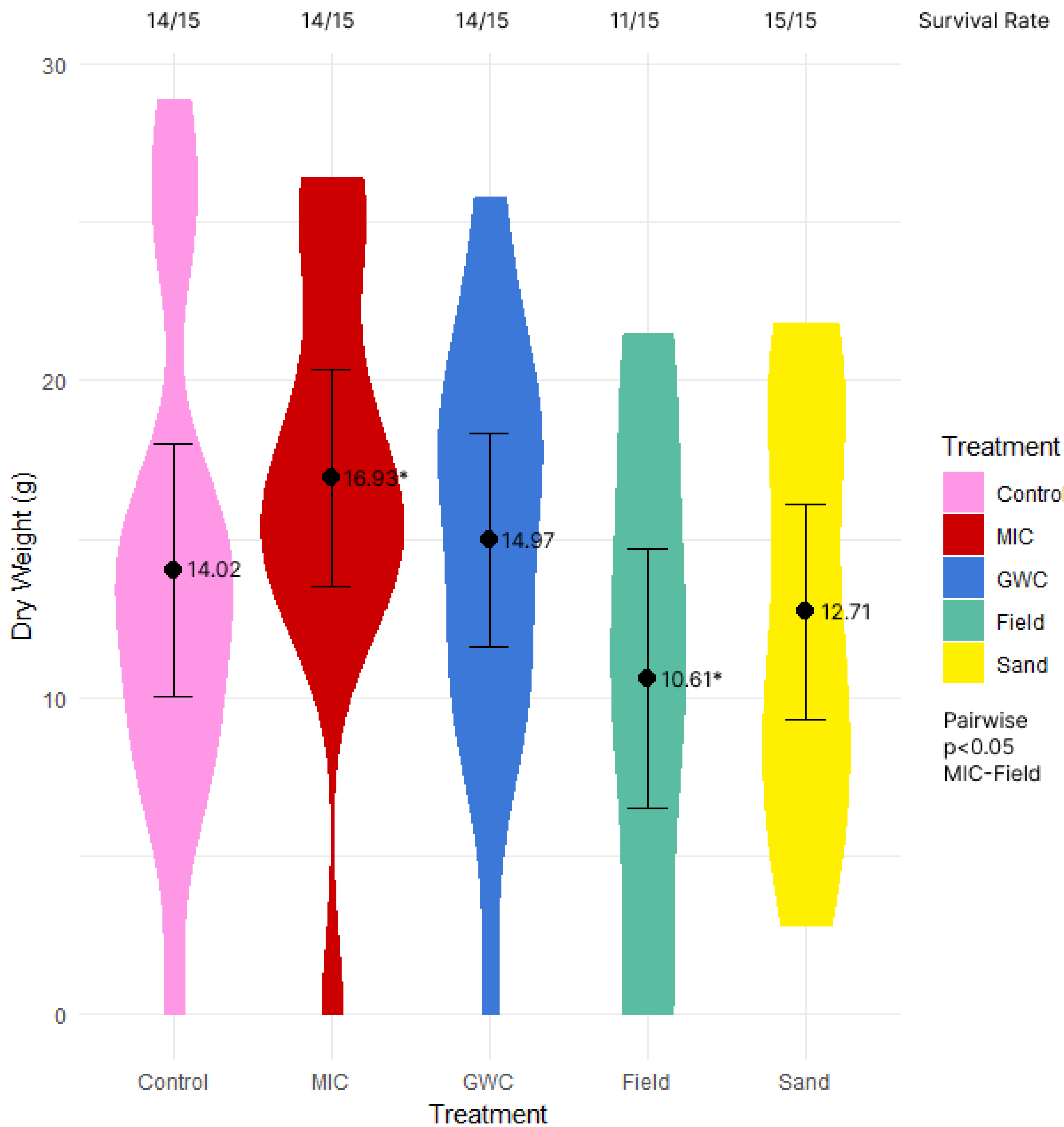

Figure 23 . Above-ground dry weight after the 12-week finishing period in three growing seasons (2020, 2021, 2022) for *Penstemon rostriflorus*. MIC = microbial-inoculated compost. GWC = green waste compost.

2.4 Conclusion

While growers may feel that adding amendments to their potting mixes gives their plants a competitive edge in the retail setting, our data demonstrate that native herbaceous plant taxa have varying responses to compost, sand, and field soil amendments. Furthermore, plant growth response to compost varies by type of compost and plant taxa. This can make it hard to make generalizations about protocols, and indicates that further research is needed on a wider range of plants.

Some taxa show increased mortality due to disease pressure in container cultivation. In this study, those taxa included *Penstemon pinifolius* ‘P019S’ and *Penstemon linarioides* ssp. *coloradoensis* ‘P014S.’ Adding composts containing beneficial microbes, may help increase survivability of these plant taxa during the finishing period in container production.

While some growers add field soil to their potting mixes, our results do not support that practice. Adding field soil, even in small quantities, may introduce soil-borne pathogens and decrease drainage capacity through migration of silt and clay particles through the substrate (Hoitink and Kuter, 1986) (Landis, 1990). While research supports the use of transplanting field soil with high levels of beneficial microbes into degraded field soils that are in the process of restoration (Koziol et al., 2021), our results suggest that use of field soils in container cultivation can lead to plant stress and lower survival rates.

In comparison with the control, adding sand at 30% by volume resulted in a slight increase in dry weight of above-ground biomass for four of our study taxa: *Andropogon gerardii*, *Eriogonum umbellatum* var. *aureum* ‘Psdowns,’ *Geum triflorum*, and *Mirabilis multiflora*. These taxa all have modified stems or roots that may aid in water and nutrient uptake and storage, allowing these species to increase their biomass even in well-drained substrate. It may be beneficial to investigate other taxa with similar adaptations to evaluate their response to peat-reduced substrates in nursery container production.

Many of our native herbaceous perennial taxa, including the taxa investigated in this study, show great variability within each taxon in regards to change in growth and biomass, but very little variability among treatments. Since native herbaceous species are not significantly impacted by amendments that replace peat in growing media mixes, perhaps further reduction of peat-based media constituents can aid growers in bringing a more marketable and sustainable product to consumers, who often select this plant material for ecosystem benefits and conservation awareness.

Some consumers are willing to pay a premium of 8-14% for locally-sourced native plants (Curtis and Cowee, 2010) yet Brzuszek and Harkess (2009) found that only 50% of nurseries label their native plants as such. While growers may add amendments to containers during the finishing period in hopes of achieving better survivability and more visually appealing plants, our results indicate that for many taxa, there may not be significant responses in plant growth. Therefore, growers could focus on reducing peat without risking significant impacts on plant growth, and they could adapt merchandising tools to market these plants for their sustainable production, ecosystem benefits, and resilience in the landscape.

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Appendix Grower Survey Questions and Taxa

Survey Questions

1. How long have you been propagating/growing Plant Select® plants?
2. Which of the following Plant Select® plants have you grown before? (Please select all that apply)
3. Which of the following Plant Select® plants have you had success with looking good in containers? (Please select all that apply)
4. Please provide specific details (i.e. substrate types, watering regime, additives, etc.) on how you obtained your success with the species below.
5. Would we be able to contact you later for follow up questions on your growing techniques? If so, please share the email and/or phone number to reach you.
6. Do you have any other comments, questions, or concerns?

Taxa included in the grower survey for questions 2-4

WINDWALKER® big bluestem, *Andropogon gerardii* 'PWIN01S'

Mock Bearberry manzanita, *Arctostaphylos* x *coloradensis*

Panchito manzanita, *Arctostaphylos* x *coloradensis* ‘Panchito’

Chieftain manzanita, *Arctostaphylos* x *coloradensis* ‘Chieftain'

Prairie Lode sundrops, *Calylophus serrulatus* 'Prairie Lode'

Snow Mesa buckwheat, *Eriogonum wrightii* var. *wrightii*

Prairie Smoke, *Geum triflorum*

Goldhill golden-aster, *Heterotheca jonesii* x *villosa* 'Goldhill'

Waxflower, *Jamesia americana*

Meadow Blazingstar, *Liatris ligulistylis*

Dotted Blazing Star, *Liatris punctata*

SILVERTON® bluemat penstemon, *Penstemon linarioides* ssp. *coloradoensis* 'P014S'

Grand Mesa beardtongue, *Penstemon mensarum*

SteppeSunsTM Sunset Glow Penstemon, *Penstemon pinifolius* ‘P019S'

Desert beardtongue, *Penstemon pseudospectabilis*

Bridges' penstemon, *Penstemon rostriflorus*

Smith's buckthorn, *Rhamnus smithii*

Thin Man Indian grass, *Sorghastrum nutans* 'Thin Man' PPAF

VALLEY LAVENDER® plains verbena, *Verbena bipinnatifida*

Golden flowered prairie zinnia, *Zinnia grandiflora* 'Gold on Blue'