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SEASONAL GROWTH PERFORMANCE OF "GAMLIN" AND "RA'NO" SWEET ORANGE CULTIVARS GRAFTED ON MEYER AND MANZUR LEMON ROOTSTOCKS

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ABSTRACT

Rootstock choice can strongly influence vegetative development of grafted citrus nursery plants, but local rootstock–scion responses must be evaluated for individual cultivar combinations. This study describes seasonal growth of the sweet orange cultivars 'Gamlin' and 'Ra'no' grafted on Meyer and Manzur lemon rootstocks under greenhouse conditions from June 1 to November 15, 2025. The stated design comprised two cultivars, two rootstocks, four biological replicates, 12 sampling dates, and measurements at the root collar and at 10, 20, and 30 cm stem positions. This structure corresponds to 16 plants, 192 plant-date records, and 768 position-level observations. Across the archived repeated observations, all four cultivar–rootstock combinations increased during the season. Descriptive final values favored Meyer rootstock: averaged across cultivars and stem positions, the final recorded growth measurement was 25.93 for Meyer compared with 17.67 for Manzur, and the mean absolute seasonal increase was 18.97 compared with 11.10, respectively. The largest absolute increase was observed for 'Ra'no' × Meyer at the root collar (26.12), whereas the largest final value occurred for 'Gamlin' × Meyer at 30 cm (34.75). These findings indicate greater vegetative development on Meyer under the conditions represented in the archived dataset. Because the original plant-level repeated-measures dataset was not available for re-analysis, previous factorial ANOVA, correlation, principal component, and cluster results are not treated as confirmatory evidence in this revision.

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Introduction

Sweet orange (Citrus sinensis) is commonly propagated by grafting, so nursery and orchard performance reflects the combined effects of the scion genotype, rootstock genotype, environment, and management. Rootstocks can influence tree vigor, size, nutrient relations, stress responses, and productivity, which makes rootstock selection a central decision in citrus production (Carvalho et al., 2024; Kunwar et al., 2023; Roberto et al., 2022). Rootstock effects are not universal: the same rootstock can produce different outcomes with different scions or under different environmental conditions. Consequently, locally relevant comparisons are needed before a rootstock is recommended for a specific cultivar or nursery system.

Several mechanisms have been proposed to explain rootstock-mediated changes in scion growth. Root system architecture, hydraulic conductance, nutrient acquisition, vascular development, and long-distance signaling can all contribute to differences in shoot vigor (Biasuz & Kalcsits, 2023; Mauro et al., 2022; Wang et al., 2025). These mechanisms should, however, be distinguished from the direct evidence provided by a growth experiment. Greater stem development alone can demonstrate a difference in vegetative performance, but it cannot by itself establish superior hydraulic conductivity, nutrient uptake, hormone transport, or graft compatibility. Direct physiological or anatomical measurements are needed to support those mechanistic conclusions.

Time-resolved measurements are useful because a single endpoint cannot describe the course of nursery development. Repeated measurements can reveal whether treatments differ mainly in early growth, mid-season acceleration, or late-season stabilization. Measurements at several stem positions can also describe how growth is distributed along the plant. Multivariate and inferential approaches can be informative when the underlying experimental unit and repeated-measures structure are modeled correctly, but repeated observations on the same plant are not statistically independent. A valid inferential analysis therefore requires plant identifiers and a repeated-measures or mixed-effects model rather than an ordinary factorial analysis that treats every observation as independent.

The archived study compared two sweet orange cultivars, ‘Gamlin’ and ‘Ra’no’, grafted on Meyer and Manzur lemon rootstocks. The practical question was whether the two rootstocks were associated with different seasonal vegetative development and whether the response depended on cultivar and stem position. The present revision has three objectives: (a) to present the archived growth results with corrected sample accounting and consistent cultivar naming, (b) to restrict conclusions to effects that are directly supported by the available measurements, and (c) to provide a statistically defensible framework for confirmatory re-analysis when the plant-level dataset becomes available.

Method

Study Design

The experiment was conducted under greenhouse conditions during the 2025 growing season. Two sweet orange cultivars (‘Gamlin’ and ‘Ra’no’) were evaluated on two lemon rootstocks (Meyer and Manzur), producing four cultivar–rootstock combinations. Four biological replicates were stated for each combination. Measurements were collected on 12 dates from June 1 through November 15, 2025, at the root collar and at 10, 20, and 30 cm stem positions. On the basis of the stated factorial structure, the experiment contained 16 biological plants, 192 plant-date records (16 plants × 12 dates), and 768 position-level measurements (192 plant-date records × 4 positions). The previously stated total of 96 plant-date records was an arithmetic inconsistency and is corrected here.

Plant Material and Nursery Conditions

The archived manuscript identifies the scions as ‘Gamlin’ and ‘Ra’no’ sweet orange and the rootstocks as Meyer and Manzur lemon materials propagated in a greenhouse nursery. It does not document the exact greenhouse location, plant age at grafting, grafting method and date, rootstock cutting age, container volume, substrate composition, irrigation schedule, fertilizer program, pest-management program, temperature, relative humidity, or light regime. These variables can influence citrus growth and should be restored from the original nursery records before submission to a journal that requires full experimental reproducibility. No values for these missing conditions have been invented in this revision.

Growth Measurements

Measurements were recorded at the root collar and at fixed positions 10, 20, and 30 cm along the stem. The archived manuscript repeatedly describes the response as stem growth or stem thickening and labels the numerical unit as centimeters. However, the measurement instrument and the exact dimensional trait (e.g., diameter, circumference, or another stem-growth metric) are not specified. Accordingly, this revision refers to the response as the stem growth measurement and retains the unit exactly as recorded in

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the archived dataset. The underlying field sheets should be checked before publication to verify both the trait definition and unit.

Data Integrity and Statistical Analysis

Descriptive values were taken from the archived treatment table, which reports initial value, final value, absolute seasonal increase, and percentage increase for each cultivar × rootstock × position combination. Treatment-level summaries were recalculated from those reported values. The principal descriptive outcomes are the final measurement and absolute seasonal increase because percentage change can become very large when the initial value is small, as occurred for some cells.

Confirmatory factorial ANOVA, Pearson correlation, principal component analysis, Ward clustering, and simple regression are not reproduced as inferential evidence in this revision. The design contains repeated observations on the same biological plants across both dates and stem positions, so ordinary analyses that assume independent observations would underestimate within-plant dependence. A defensible confirmatory analysis should use the plant as the experimental unit, include plant identity as a random effect, treat date and position as within-plant factors, and consider an appropriate within-plant covariance structure (for example, autoregressive correlation across dates). Estimated marginal means, 95% confidence intervals, and multiplicity-adjusted contrasts should then be reported. Because the raw plant-level records were not contained in the uploaded manuscript, such a mixed-effects analysis cannot be reconstructed without inventing data.

Results

Seasonal Growth Pattern

The archived repeated-observation plot showed increasing mean growth over the June-to-November period for all four cultivar–rootstock combinations. Growth was comparatively slow during the earliest observations, increased more strongly during the middle of the season, and approached a plateau toward the final observations. The Meyer-grafted combinations ended the season at higher overall mean levels than the corresponding Manzur-grafted combinations. Because the plant-level longitudinal records were unavailable, these temporal patterns are reported descriptively rather than as statistically tested differences in slopes or date-by-treatment interactions.

Table 1

Experimental Structure and Corrected Observation Counts

Component	Level/Count	Comment
Cultivars	2	‘Gamlin’ and ‘Ra’no’
Rootstocks	2	Meyer and Manzur lemon
Cultivar × rootstock combinations	4	Four treatment combinations
Biological replicates	4 per combination	16 plants total
Sampling dates	12	June 1–November 15, 2025
Stem positions	4	Root collar; 10, 20, and 30 cm
Plant-date records	192	16 plants × 12 dates
Position-level observations	768	192 plant-date records × 4 positions

Note. The 192 plant-date count follows directly from the stated 2 × 2 × 4 × 12 design.

Final Growth Profiles

Final values and seasonal changes differed substantially among cultivar–rootstock combinations and stem positions (Table 2). The largest final recorded value was 34.75 for ‘Gamlin’ × Meyer at the 30 cm position. The same combination reached 30.05 at the root collar. ‘Ra’no’ × Meyer reached final values of 30.00 at the root collar, 26.80 at 10 cm, 27.00 at 20 cm, and 17.23 at 30 cm. In contrast, ‘Ra’no’ × Manzur produced lower final values at the root collar (12.80) and 30 cm position (13.78).

The largest absolute seasonal increase was observed for ‘Ra’no’ × Meyer at the root collar (26.12), followed by the same combination at 20 cm (24.88), ‘Gamlin’ × Meyer at the root collar (22.05), and ‘Gamlin’ × Meyer at 30 cm (21.12). The smallest absolute increase occurred for ‘Ra’no’ × Manzur at the

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root collar (5.68). These values show that the effect associated with rootstock was not identical at every stem position and that cultivar-specific spatial patterns were present.

Descriptive Rootstock Contrasts

Averaged across the eight cultivar × position cells for each rootstock, the final measurement was 25.93 for Meyer and 17.67 for Manzur. Thus, the Meyer average was approximately 46.8% higher on this descriptive scale. The corresponding mean absolute seasonal increase was 18.97 for Meyer and 11.10 for Manzur, a descriptive difference of approximately 70.8%. Within 'Gamlin', the mean final value across positions was 26.60 on Meyer and 19.88 on Manzur; within 'Ra'no', the corresponding values were 25.26 and 15.46. These summaries consistently favor Meyer for the recorded growth outcome, but they should not be interpreted as inferential effect estimates until the repeated-measures model is fitted to the raw replicate data.

Cultivar- and Position-Specific Responses

The two cultivars displayed different spatial patterns. 'Gamlin' × Meyer showed particularly strong development at the 30 cm position, whereas 'Ra'no' × Meyer showed its largest absolute increases at the root collar and 20 cm position. The response to Manzur was also cultivar dependent: 'Gamlin' × Manzur retained a relatively high final value at 30 cm (26.15), whereas 'Ra'no' × Manzur was lowest at the root collar and 30 cm. These contrasts support a cautious interpretation of rootstock–scion interaction at the descriptive level and argue against classifying either rootstock as uniformly vigorous or weak across all positions and cultivars.

Discussion

The principal descriptive result is that plants grafted on Meyer rootstock showed greater recorded vegetative development than plants grafted on Manzur across most cultivar–position comparisons. This pattern is consistent with the broader citrus literature showing that rootstock genotype can materially alter scion vigor and tree size (Carvalho et al., 2024; Kunwar et al., 2023). Rootstock-associated differences can arise through multiple physiological pathways, including water relations, nutrient acquisition, vascular properties, and signaling, but the present dataset measured growth rather than those underlying mechanisms (Biasuz & Kalcsits, 2023; Wang et al., 2025). Consequently, the most defensible conclusion is that Meyer was associated with greater vegetative growth under the tested nursery conditions, not that Meyer was proven to have greater hydraulic conductivity, nutrient-use efficiency, cambial activity, or hormone transport.

The strong performance of 'Ra'no' × Meyer at the root collar and 20 cm position and of 'Gamlin' × Meyer at 30 cm illustrates why multiple stem positions can be informative. Growth along a young grafted plant is not necessarily uniform. Position-specific differences may reflect developmental timing, internode structure, radial expansion, or assimilate allocation, but these possibilities remain hypotheses in the absence of anatomical and physiological measurements. The observed differences can nevertheless be useful for nursery screening because they reveal where along the stem the combinations diverged most strongly.

The descriptive superiority of Meyer should also not be equated automatically with graft compatibility. Graft compatibility is a broader biological property that can involve survival, graft-union anatomy, vascular continuity, mechanical integrity, long-term growth balance, and the absence of delayed incompatibility symptoms (Mauro et al., 2022; Wang et al., 2025). Short-term vegetative vigor is relevant to nursery performance, but greater growth alone is insufficient to establish compatibility. Future evaluations should therefore combine growth with graft-union observations and, ideally, longer-term survival and orchard performance.

The present study also demonstrates the importance of aligning statistical analysis with experimental design. Twelve dates and four stem positions provide rich repeated information, but they do not create 768 independent biological replicates. The biological replication remains the number of

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independent plants. A mixed-effects analysis of the original plant-level data would allow the contributions of cultivar, rootstock, date, and position to be estimated while correctly accounting for repeated observations within each plant. Such an analysis could also test whether the apparent Meyer advantage is stable across dates or varies during particular phases of seasonal development.

Multivariate techniques such as principal component analysis and hierarchical clustering can be useful exploratory tools, but they should be based on clearly defined observational units. If only four treatment centroids are entered, the resulting separation is descriptive and should not be presented as independent confirmation of biological effects. A stronger future approach would derive plant-level features—such as initial value, final value, absolute increase, and time-course slope for each position—and then apply exploratory multivariate analysis to the independent plants. This would preserve biological replication and make cluster or ordination patterns easier to interpret.

For nursery practice, the current results provide preliminary support for Meyer as the more vigorous of the two tested rootstocks for these orange cultivars under the represented greenhouse conditions. Whether greater vigor is desirable depends on production goals. Rapid nursery growth can shorten production cycles, but excessively vigorous rootstocks may not always be optimal for orchard density, canopy management, or long-term yield efficiency. Rootstock selection should therefore integrate nursery growth with subsequent field performance, fruit production, stress tolerance, and site adaptation (Roberto et al., 2022).

Limitations and Priorities for Confirmatory Work

Four limitations should be addressed before journal submission. First, the raw plant-level repeated-measures dataset should be recovered and analyzed with an appropriate mixed-effects model. Second, the exact measurement trait and unit must be verified from field records; the archived manuscript labels the response in centimeters but does not define whether it is diameter, circumference, or another metric. Third, the greenhouse and nursery protocol must be completed with location, plant age, grafting procedure, containers, substrate, irrigation, fertilization, pest management, and environmental conditions. Fourth, conclusions about physiological mechanisms and graft compatibility should remain explicitly tentative unless supported by direct measurements. These additions would convert the present descriptive revision into a fully reproducible confirmatory experiment.

Conclusion

Across the archived 2025 greenhouse observations, both sweet orange cultivars increased in the recorded stem growth measurement on both rootstocks, but the largest final values and seasonal increases were generally associated with Meyer. ‘Ra’no’ × Meyer produced the greatest absolute increase at the root collar (26.12), while ‘Gamlin’ × Meyer produced the largest final value at the 30 cm position (34.75). Averaged descriptively across cultivars and positions, Meyer exceeded Manzur in both final measurement and absolute seasonal increase. These findings support Meyer as a promising rootstock for vigorous nursery development of the tested cultivars under the represented conditions. They do not, by themselves, prove superior physiological efficiency or graft compatibility. Recovery of the raw repeated-measures dataset and missing nursery metadata is required for a definitive inferential assessment and fully reproducible journal submission.

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