The Quality Index – A New Tool for Integrating Quantitative Measurements to Assess Quality of Young Floriculture Plants

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Abstract
Floriculture crops are an important sector of ornamental horticulture, with an estimated wholesale value in the United States (U.S.) of US$ 4.13 billion in 2010. Furthermore, the value of propagative materials for these crops is US$ 376 million. The majority of floriculture crop producers utilize young plants including seedlings (plugs) or rooted stem-tip cuttings (liners) produced by propagation specialists and shipped to producers for finishing. Research has focused on improving the efficiency and quality of young plants production, since the advent of the “plug revolution” and increasing popularity of annuals produced from stem-tip cuttings has provided many challenges and opportunities in young plant production. Numerous quantitative measurements of seedlings and rooted cuttings are taken to measure the effects of environmental and/or cultural treatments during propagation. However, of greater importance to young plant producers is the cumulative effect of quantitative parameters on young plant quality. To resolve this, a subjective rating based on perceived visual quality is sometimes used. Here we present the Quality Index (QI), a tool integrating several quantitative measurements and indices to provide an objective assessment of young plant quality. For example, we found that when the daily light integral is increased during propagation of seeds and cuttings of new and current floriculture crops, the QI of young plants increased by up to 858%. We will introduce this concept and discuss the applications, opportunities, and limitations of using the QI for assessing the effects of environmental and/or cultural conditions during propagation of young plant quality in floriculture production.

INTRODUCTION
Rooted cuttings (liners) and seedlings (plugs) comprise a valuable sector of the global floriculture market. The use of young plants (plugs and liners) allows growers the ability to increase the consistency of their crop and minimize post-transplant finishing time. An increase in the popularity and use of young plants in the past few decades has resulted in more research regarding the effects of environmental conditions and cultural practices on the growth, development, and performance of plugs and liners. For example, research on cutting propagation of herbaceous annual bedding plants has focused on the effects of temperature and duration during shipping on cuttings (Lopez and Runkle, 2008) and environmental and cultural conditions during propagation, including substrate composition (Giselrød, 1983), misting (Graves and Zhang, 1996; Wilkerson et al., 2005a), substrate temperature (Wilkerson et al., 2005b), and mineral nutrition (Santos et al., 2008, 2009). In these studies morphological data were collected and, while the quality of rooted cuttings was not measured, many of the data reported reflect the quality of young plants. For example, important characteristics of seedlings and rooted cuttings include overall growth or biomass accumulation during propagation, the relative amount of root and shoot biomass (R:S ratio), and thickness of stems for easier handling and transplanting (Lopez and Runkle, 2008; Pramuk and Runkle, 2005). These types of data influence the quality and performance of young plants.
We may look to the reforestation and afforestation literature from greenhouse and nursery production of tree seedlings for a more comprehensive and integrated morphological assessment of young plant quality (Ritchie, 1984, 2010; Mattsson, 1996; Thompson, 1985). Forest nursery scientists have developed quantitative indices that integrate morphological traits correlated to outplanting success, including the “Dickson Quality Index” (Dickson et al., 1960). The quality index (QI) was originally designed for assessing the quality of *Picea abies* (L.) H. Karst. and *Pinus strobus* L. seedlings (Dickson et al., 1960), and is a product of the total dry mass (TDM) divided by the sum of the shoot: root dry mass ratio (S:R) and ratio of stem caliper to stem length (sturdiness quotient; SQ), or QI = TDM/(S:R + SQ). Because these data are frequently collected in young floriculture crop research, an integrated index such as QI provides a tool to easily and objectively measure young plant quality.

We have found no reports using any indices such as the QI to assess the quality of young herbaceous floriculture propagules. Therefore, our objective with this research was to evaluate the potential of the QI as an integrated, quantitative measurement of seedling and rooted cutting quality.

**MATERIALS AND METHODS**

**Experiment 1**

Seeds of *Tecoma stans* (L.) Juss. ex Kunth ‘Mayan Gold’ (Pan American Seed, West Chicago, IL, USA) were sown on 13 Feb. 2009, 23 June 2009, and 15 Jan. 2010 in 72-cell plug trays (44-mL individual cell volume; Dillen Products, Middlefield, OH, USA) filled with a commercial soilless medium composed of (v/v) 70% Canadian sphagnum peat moss and 30% perlite (Super Fine Germinating Mix; Conrad Fafard, Anderson, SC, USA). Seeds were covered with a thin layer of vermiculite (Sunshine; SunGro Horticulture, Bellevue, WA, USA) to maintain moisture and were irrigated as necessary with acidified water supplemented with water-soluble fertilizer (Peters Excel® Cal-Mag© 15N–2.2P–12.5K; Scotts Co., Marysville, OH, USA) to provide 100 mg·L⁻¹ N with every watering beginning at sowing.

The greenhouse air temperature set point was a constant 23°C. A 16-h photoperiod (5 am to 9 pm) was maintained with natural day lengths and day-extension lighting provided by high-pressure sodium (HPS) lamps (e-system HID; PARsource, Petaluma, CA, USA). An automatic woven shade curtain was retracted when the outdoor light intensity reached 1000 µmol·m⁻²·s⁻¹ (OLS 50; Ludvig Svensson Inc., Charlotte, NC, USA) throughout the study to prevent leaf scorch.

Immediately after sowing, seeds were placed under daily light integral (DLI) treatments created in the propagation environment with the combination of supplemental light provided by HPS lamps and fixed woven shade cloths placed above individual propagation compartments that reduced light by 30, 50, or 70% (DeWitt Company, Sikeston, MO, USA) or no shade.

Five weeks after sowing, fifteen seedlings per DLI treatment were randomly harvested for data collection. Stem caliper above the lowest leaf and stem length from the surface of the substrate to the stem tip were measured with a digital caliper (digiMax; Wiha, Schonach, Germany). Roots were excised and roots and shoots were dried separately in an oven at 70°C for 3 d then weighed. Total dry mass (TDM; shoot dry mass + root dry mass), root: shoot dry mass ratio (R:S; root dry mass/stem dry mass), a modified version of the sturdiness quotient (SQ; shoot length/stem caliper) (Thompson, 1985), and a modified version of the Quality Index [QI = TDM × (R:S + SQ)] (Dickson, 1960) were calculated. Data were analyzed using regression analysis (SPSS 17.0; SPSS, Inc., Chicago, IL, USA) with DLI as the independent variable.

**Experiment 2**

‘Wink Coral’, Lantana camara L. ‘Lucky Gold’, Nemesia fruticans (Thunb.) Benth. ‘Aromatica Royal’, Osteospermum ecklonis (DC.) Norl. ‘Voltage Yellow’, Scaevola L. hybrid ‘Blue Print’, Sutera cordata Roth. ‘Abunda Giant White’, and Verbena Ruiz ×hybrida ‘Aztec Violet’ were harvested from stock plants. Forty uniform 2.5-cm shoot-tip were placed in 105-cell propagation trays (28-mL individual cell volume; T.O. Plastics, Inc., Clearwater, MN) filled with a propagation substrate composed of (v/v) 50% soilless substrate (Fafard 1P; Conrad Fafard, Inc.) and 50% coarse perlite (Strong-Lite Coarse Perlite; Sun Gro Horticulture) on 4 Sept. 2010, 16 Oct. 2010, and 11 Jan. 2011. Cuttings were sprayed to runoff with a solution containing 300 mg·L⁻¹ non-ionic surfactant (CapSil; Aquatrols, Paulsboro, NJ, USA) so that water would not accumulate on the plant foliage. All cuttings were placed in a glass-glazed greenhouse under a 16-h photoperiod with air and substrate temperature set points of 23°C and a DLI maintained at ≈5 mol m⁻²·d⁻¹ for callusing.

After 7 d of callusing, ten cuttings of each species were placed under 12 DLI treatments were created in the propagation environment with the combination of supplemental light provided by HPS lamps and fixed woven shade cloths placed above individual propagation compartments that reduced light by 0, 38, 61, 86% (XLS F-14, -15, or -16; Lundvig Svensson, Inc.). An automatic woven shade curtain was retracted as previously described. Mist was applied consisting of tap water supplemented with a water-soluble fertilizer (Jack’s LX 16N–0.94P–12.3K Plug Formula for High Alkalinity Water; J.R. Peters, Inc., Allentown, PA, USA) to provide 50 mg·L⁻¹ N with each misting.

Data were collected 14 d after cuttings were placed under DLI treatments as described under Experiment 1. The experiment employed a randomized complete block design in a factorial arrangement. The factors were DLI (12 levels) and species (9 levels). The experiment was replicated three times over time with 10 samples (individual cuttings) per species per DLI per replication. Data were analyzed using regression analysis (SPSS 17.0; SPSS, Inc., Chicago, IL, USA) with DLI as the independent variable.

RESULTS

Experiment 1

Total dry mass for Tecoma increased linearly from 15 to 177 g as the DLI during propagation increased from 0.75 to 25.2 mol·m⁻²·d⁻¹, respectively (data not shown). The R:S ratio of Tecoma increased quadratically from 0.43 to 1.9 as propagation DLI increased from 0.75 to 25.2 mol·m⁻²·d⁻¹ (data not shown). The SQ increased as DLI during propagation increased to ca. ≈10-20 mol·m⁻²·d⁻¹ and decreased as DLI increased beyond that range (data not shown). As DLI increased to 25.2 mol·m⁻²·d⁻¹ the QI of Tecoma seedlings increased quadratically (Fig. 1).

Experiment 2

Total dry mass increased with DLI during propagation for all species in this study, though the magnitude of response to DLI varied with species. For example, while TDM of Lantana increased by 115 mg (64%) as DLI during propagation increased from 1.2 to 12.3 mol·m⁻²·d⁻¹, TDM of Diascia increased by 151 mg (465%) as DLI increased (data not shown). Additionally, the R: S ratio increased for all species as DLI during propagation increased, ranging from 18% (Verbena) to 329% (Osteospermum) and 419% (Scaevola) (data not shown). Daily light integrals during propagation affected the sturdiness quotient of species differently. Though the sturdiness quotient of Nemesia increased by 58% as DLI during propagation increased from 1.2 to 12.3 mol·m⁻²·d⁻¹, several species were unaffected by DLI during propagation (data not shown). The QI increased for all species as DLI during propagation increased (Fig. 2A, B, and C) to different magnitudes. For example, though the quality index of Lantana increased by 63 (53%) (Fig. 2B) as DLI increased from 1.2 to 12.3 mol·m⁻²·d⁻¹, the quality index of Diascia increased by 78 (960%) (Fig. 2A).
DISCUSSION

Plant quality is a challenging parameter to characterize. Measurements made to assess plant quality may be classified into one of three categories of plant attributes: 1) morphological; 2) physiological; and 3) performance (Ritchie et al., 2010). Physiological attributes include gas exchange, chlorophyll fluorescence, and electrolyte leakage. While important for understanding some of the underlying physiology of plant growth and development, measurements of many physiological parameters are time-consuming to perform and/or require advanced equipment. Measurements of physiological attributes are not regularly performed and performance attributes such as time to flowering after transplanting can be time-, labor- and space-intensive processes. Therefore, the identification of relatively simple measurements to characterize quality attributes using morphological measurements that are correlated to subsequent growth is needed.

The original QI equation, as proposed by Dickson et al. (1960), is QI = TDM/(S:R + SQ), where SQ = stem caliper/stem length. Using this formula, smaller S:R ratios and SQ indicate greater root mass relative to shoot mass and sturdiness, respectively. While this is perfectly acceptable, it is not intuitive. By rearranging the original QI equation to incorporate the R:S ratio and SQ where SQ = stem length/stem caliper, there is a more intuitive relationship between perceived quality because larger values indicate a more desirable phenotype. Therefore, we rearranged the QI [QI = TDM × (R:S + SQ)] in our study to accommodate this more intuitive relationship between QI parameters and their respective values.

Though we feel that the QI is very useful for providing a quantitative measure of young plant quality, there are certainly limitations when using the QI. Most notably, the QI is determined using solely morphological measurements and does not include measurements that assess physiological or performance attributes. While the morphological data integrated into the QI were originally selected because they were strongly correlated to outplanting success of tree seedlings, the greenhouse environment where bedding plants are grown is not an adverse environment to the degree that outdoor planting sites may be. However, these data still reflect the morphological attributes that contribute to our perception of quality of a crop and subsequent growth in the greenhouse (Currey et al., 2012; Pramuk and Runkle, 2005).

Additional opportunities exist to modify the QI to include a broader suite of traits of interest to young floriculture crop producers or emphasize important traits. For instance, the QI does not include variables for other morphological traits of interest in floriculture crop production such as branch and/or node (leaf) number. Furthermore, variables could be weighted with coefficients to emphasize or deemphasize traits based on their relevance. The formula for the QI, as used in our research, may be used as a starting point and could be modified to include or weight other variables of interest.

CONCLUSIONS

The QI provides an objective rating of young plant quality by integrating morphological parameters that contribute to the perceived quality of plugs and liners. There are clearly limitations to the use of QI, as well as opportunities to expand the index to include other attributes of plant quality. However, we hope that introducing the concept of the QI to the floriculture crop community will provide a platform for future use and critical review of the QI for young herbaceous floriculture crops.

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Literature Cited
Fig. 1. Relationships between mean daily light integral (DLI) and quality index of *Tecoma* seedlings after 35 d under different daily light integrals during propagation. Each symbol represents the mean of 15 plants, and error bars represent SEs of the mean. *** indicates significant at $P \leq 0.001$. 
Fig. 2. (A-C) Relationships between mean daily light integral (DLI) and quality index of *Angelonia*, *Argyranthemum*, *Diascia*, *Lantana*, *Nemesia*, *Osteospermum*, *Scaevola*, *Sutera* and *Verbena* after 14 d under different DLIs during propagation. Each symbol represents the mean of 10 plants, and error bars represent SEs of the mean. *** indicates significant at \( P \leq 0.001 \).