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The Effects of Plug Cell Volume, Paclobutrazol Height Control and the Transplant Stage on the Post-transplant Growth of *Impatiens wallerana* Pot Plant

A. Di Benedetto and R. Klasman
(Cátedra de Floricultura, Facultad de Agronomía, Universidad de Buenos Aires, Buenos Aires, Argentina)

Summary

The aim of this work was to determine the effect of both nursery container volume and the use of paclobutrazol retardant associated to holding plugs on the growth of *Impatiens wallerana*, an important bedding plant, at the commercial sales stage. Our results showed an increase in dry weight and main root at the sales stage while plug cell volume increased from 512 to 50 plug cell tray (2.5 to 55.7 cm^3 $cell^{-1}$) during nursery. When the growth retardant paclobutrazol was used, a significant decrease in total dry weight has been found. Larger transplant sizes could be achieved by holding plugs two weeks from the 'optimum transplant'. The advantage of small transplants is related to lower establishment costs but, the presence of short- and long-term stresses such as the 'root restriction' imposed by small plug cell tray and/or growth regulators which inhibit plant growth overriding these economic aspects affects their suitability.

Key words. bedding plant – holding plug – *Impatiens wallerana* – paclobutrazol regulator – root restriction.

Introduction

The marketability of potted plants is greatly influenced by the quality of the produced plants. Technological advances in transplanting have contributed to the growth of the bedding plants industry by reducing costs and increasing production reliability.

Bedding plant producers have progressively adopted reduced size containers, leading to a limited soil volume available for the root system (Styer and Koranski 1997; Mugnai et al. 2000). Plastic seedling trays, with individual small cell sizes allow short plant-raising periods and have reduced costs. Smaller containers are desirable to make a better use of space and to reduce transporting and shipping costs. However, small containers may cause root restriction effects on growth and flowering, as reported for vegetables (Weston and Zandstra 1986; Ruff et al. 1987; Peterson et al. 1991; Bar-Tal and Pressman 1996) and ornamental bedding plants (Van Iersel 1997; Di Benedetto and Klasman 2004). The response of roots to mechanical impedance has occupied agriculturalists, plant biologists and soil physicists for at least the past century. The physiology of roots growing under impeded conditions is, however, only vaguely understood.

Ornamental and vegetable seedlings growing at high population densities under adequate moisture and mineral nutrients conditions become increasingly tall and etiolated; photosynthesis is reduced as a direct result of reduced photon absorption and, consequently, a reduced electron transport rate in the chloroplast. In greenhouses, the high relative humidity and lack of air movement contribute to the problem. When such spindly, tender plants are transplanted, they are susceptible to mechanical damage in the transplanting operation, and to high stress levels in the field. Preventing the rapid increase in plant height of seedlings crowded in transplant containers by the use of growth-retarding chemicals has long been seemed as an alternative.

Plant growth retardants are commonly used in the production of bedding plants in order to control plant growth and habit during production and to improve plant appearance and quality during marketing. Species vary in responsiveness to plant growth retardants and optimum rates may vary depending on cultivars or growing conditions, such as the time of application or the size of the container (Starman et al. 1994) and growing media quality (Di Benedetto and Molinari 2007). Because some compounds may inhibit root development, the application time for the growth regulator is one of the key factors in the success of growing quality plug seedlings.

Under ideal conditions, seeds are germinated, and plugs are transplanted when they reach the correct size. Bedding plants sales are limited by the weather; for example, rainy days decrease sales and alter the grower crop program. Unfortunately, plugs are often ready for transplanting before a grower can transplant them (two weeks or longer past transplant stage) (Styer and Koranski 1997). Age of transplants and stunting of seedlings before transplanting have been suggested as common troubles for pot bedding plant production.

The aim of the following research was to determine the effect of both nursery container volume and the use of paclobutrazol retardant associated to different supraoptimum transplant times on the growth of *Impatiens wallerana*, an important bedding plant, at the commercial sales stage.

Materials and Methods

Impatiens wallerana 'Accent White' (Goldsmith Ind., U.S.A.) seeds were germinated and grown on plastic plug trays (Blackmore Inc. U.S.A.) with 50, 128, 288 and 512 cells tray^{-1} (55.70; 17.37; 6.18 and 2.50 cm^3 cell^{-1} respectively) from middle spring to summer at greenhouse facilities from Buenos Aires University campus, Argentina (34 °28 'S). A Fafard Growing Mix® substrate (Canadian *Sphagnum* peat moss-perlite-vermiculite 70:20:10 v/v) has been used.

Paclobutrazol was sprayed when plants showed the 2nd true leaves at a rate of 5 ppm and a volume of 2 l m^{-2} has been applied.

When plants reached the transplant stage, that is to say, when 4th true leaves pair were expanded, twenty plants for each plug tray (with and without paclobutrazol treatment) were transplanted into 800 cm^3 pot^{-1}. The same procedure was repeated one and two weeks later.

Plants were harvested at both transplant and sales stages (twenty replicates each); they were dried at 80 °C for 48 h and weighed. At this time, the main root length was recorded from the crown of the plant to the root top.

Plants were irrigated as needed, using intermittent overhead mist and a weekly soil fertilization according to Styer and Koranski (1997) (Stage 2: 50 ppm N; Stage 3–4: 100 ppm N; pot: 150 ppm N) was included.

The Experiment was repeated twice. A factorial design with four plug cell numbers with and without paclobutrazol retardant for three transplant dates was used. Data were subjected to analysis of variance and means were separated by Tukey test ($p \leq 0.05$).

Results

Our results showed that there was an increase in total dry weight (g plant^{-1}) at the transplant stage while the time to transplant was delayed (Fig. 1). Dry weight differences from plants grown in trays with decreasing plug cell volume have been increased too. When the growth retardant paclobutrazol was used, a similar pattern has been found; although this treatment determined a significant decrease in total dry weight ever.

Total dry weight at the pot sales stage (Fig. 2) showed only minor differences related with plug cell numbers per tray for the first transplant date (C_1), but a significant higher dry weight for 128 and 50 cells trays for the second transplant date (C_2) was found. At the third transplant date (C_3), plantlet grown at 50 cells tray showed the highest total dry weight. On the other hand, in all plug cell volume and transplant dates tested, plants sprayed with paclobutrazol regulator significantly decreased total dry weight at the sales stage.

Main root length in the transplant stage (Table 1) increased while plug cell volume increased; differences were significant for plantlet from 128 cells tray and highest when 50 plug tray was used for the three transplant dates tested. A similar pattern was found in plants which were sprayed with the paclobutrazol retardant, but there were no significant differences for plug cell volume at every transplant date with and without paclobutrazol treatment. At the sales stage (Table 1), main root length increased from 512 to 50 plug cell trays. The use of paclobutrazol retardant previously to the transplant stage decreased main root length too; this effect was statistically significant for plug cell volume at each transplant dates.

Discussion

Plants have developed a variety of strategies and mechanisms to react to any change of their environment. Anatomical and physiological adaptations allow better growth under unfavorable conditions. The root system is particularly affected by these changes because the root is that part of the plant which is in direct contact to the soil substrate (Degenhardt and Gimmler 2000).

Transplant production requires an understanding of the growth of seedlings in dense plant communities, the fac-

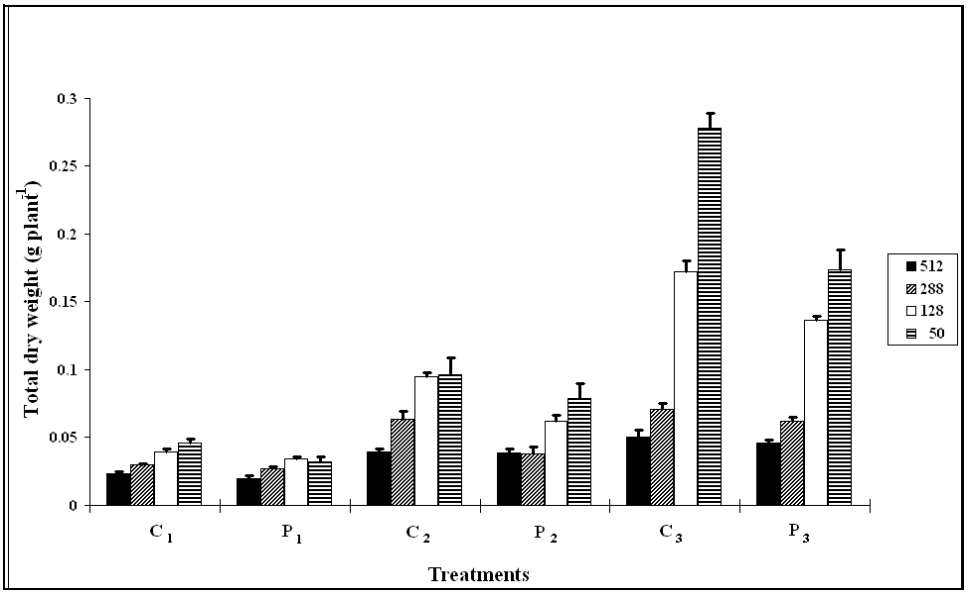


Fig. 1. Total dry weight at the end of the plug transplant stage for *Impatiens wallerana* seedlings propagated in four plug cell volume (512, 288, 128 and 50 cells tray^{-1}), with (P) and without (C) paclobutrazol treatment at three ($n_{1, 2, 3}$) transplant dates. Bars are means of twenty replicates and standard errors are indicated.

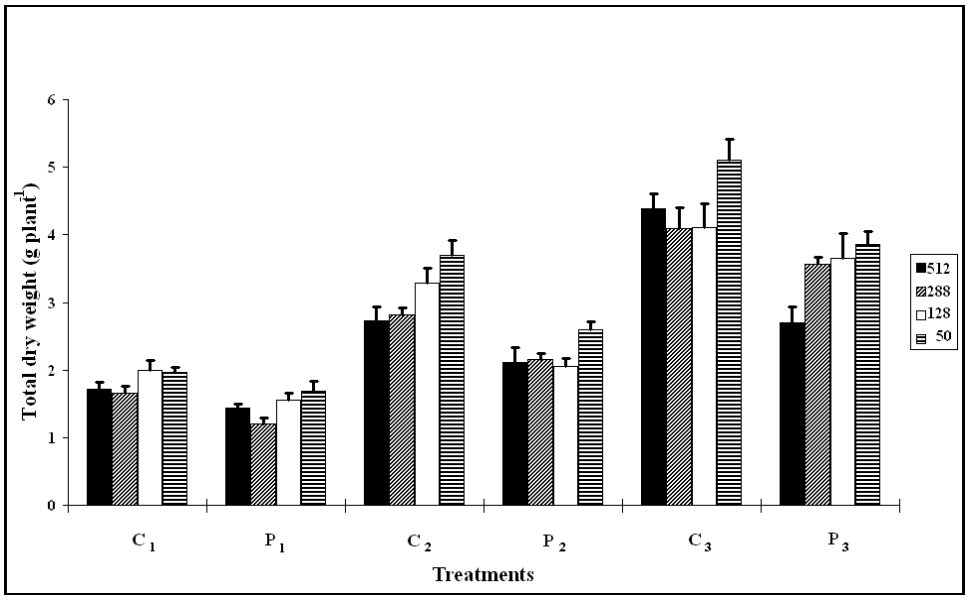


Fig. 2. Total dry weight at the end of sales stage for *Impatiens wallerana* seedlings propagated in four plug cell volume (512, 288, 128 and 50 cells tray^{-1}), with (P) and without (C) paclobutrazol treatment at three ($n_{1, 2, 3}$) transplant dates. Bars are means of twenty replicates and standard errors are indicated.

tors that regulate the growth rate of these plants, and the stresses that they are subjected to when moved to the production environment. Decisions such as the choice of container cell size or seedbed spacing before transplanting are frequently made on the basis of economics. When seedlings are grown in typical transplant containers, growth tends to be proportional to the volume of the container cell (Fig. 1). The more the space available to the plant from the nursery, the larger it becomes after transplant and the more quickly it attains particular growth stages (Fig. 2).

Root restriction is a physical stress imposed on a root system when plants are grown in small containers. This situation leads to a pronounced decrease in both root and shoot growth of the plants (Di Benedetto and Klasman 2004). Although it has been well established that root stress induced by volume reduction severely suppresses shoot growth (Ruff et al. 1987; Carmi 1995), the physiological and biochemical processes involved are largely unknown.

The decrease in main root length (Table 1) is a typical morphological change for mechanically impeded roots. It has been recently reported the fact that post transplant growth may substantially be reduced due to the limited volume of the cells in which the plants were cultivated during the plant nursery period (Kage et al. 2000; Di Benedetto and Klasman 2004; Table 1).

Table 1. Main Root Length (cm plant^{-1}) at the transplant stage and sales stage for *Impatiens wallerana* seedlings propagated in four plug cell volume (512, 288, 128 and 50 cells tray^{-1}), with (P) and without (C) paclobutrazol treatment at three ($n_{1, 2, 3}$) transplant dates.

Cells tray^{-1}	Treatments					
	C_1	P_1	C_2	P_2	C_3	P_3
Transplant stage						
512	3.24 Ac	3.04 Ac	4.15 Ac	3.51 Ac	4.19 Ac	3.40 Ac
288	3.86 Ac	3.81 Ac	3.89 Ac	3.75 Ac	3.83 Ac	4.03 Ac
128	6.25 Ab	6.41 Ab	7.00 Ab	7.31 Ab	7.50 Ab	7.73 Ab
50	12.66 Aa	12.73 Aa	12.20 Aa	13.40 Aa	13.88 Aa	12.06 Aa
Sales stage						
512	28.09 Ac	22.64 Bb	27.38 Ab	24.75 Ba	28.36 Ab	25.03 Ba
288	32.36 Ab	32.64 Aa	27.25 Ab	23.75 Ba	27.67 Ab	22.44 Ba
128	38.50 Aa	32.38 Ba	29.10 Aa	23.38 Ba	30.25 Aa	24.68 Ba
50	38.75 Aa	34.44 Ba	29.50 Aa	24.13 Ba	32.74 Aa	24.98 Ba

A different capital letter following the mean indicates a significant difference ($p \leq 0.05$) for plug cell volume at each transplant date with and without paclobutrazol treatment. Lower case letter indicate significant difference ($p \leq 0.05$) between plug cell volumes at each transplant date.

The reduction in growth rate of plants growing in close proximity into containers is due to the interaction of several environmental factors. Above-ground, closely spaced individuals have less total light available which is richer in far-red light, than do individuals farther apart. It is a common practice in horticultural potted plant production to use chemical growth regulators for controlling shoot elongation and habit during production and to improve plant appearance and quality during marketing. The triazol growth retardant paclobutrazol is a gibberellin biosynthesis inhibitor that reduces internodal elongation below the growing meristem, not through fewer leaves or nodes (Styer and Koranski 1997). Increasing paclobutrazol concentrations has reduced plant height. Total shoot dry weight was limited primarily by stem dry weight (data not shown), which was concomitant with less stem length, but the significant decrease in total dry matter accumulation (Di Benedetto and Molinari 2007; Fig. 1) when paclobutrazol was applied, are not in agreement with previous reports and remain as far as the sales stage.

Aiken and Smucker (1996) described a functional equilibrium in root and shoot growth. This equilibrium can be attributed to compensatory growth of shoot when supplied with water and nutrients of multiple root systems. However, balanced growth could be also a result from the effects of growth-regulating hormones, which are synthesized in root and shoot tissues, and translocated to complementary organs. Plant roots can sense adverse soil conditions and, via some internal signal, transmit the condition of the soil to extending leaves, with the typically net result of a decrease in leaf elongation rates (Young et al. 1997). It is generally accepted that cytokinins are mainly produced in root tips and move via the xylem to the shoot where they would share in the control of growth and development (Dieleman et al. 1997). A multiple hormonal control in plants which include gibberellins was postulated, too (Barendse and Peeters 1995). The lower dry matter accumulation (Fig. 1 and 2) and main root length (Table 1) related to plug cell size in plants sprayed with paclobutrazol during the nursery production would indicate the presence of an endogenous hormone control mechanism associated to the root restriction phenomenon.

Larger transplant sizes can of course be achieved by growing seedlings for a longer time in the transplant containers (Fig. 1). The 'optimum transplant date' has been indicated as an undefined time during Stage 4 (Styer and Koranski 1997) but, how specific is it? Our results showed no negative effects on dry weight accumulation at the sales stage (Fig. 2) for plants from holding plugs during two weeks after roots fill the plug cell. Experiments that compared the effect of transplant age have generally corroborated the findings for container sizes (Weston and Zandstra 1986; Weston 1988). Within limits, older plants have generally produced higher early yields. It has been indicated (Nesmith 1993) that as growth is prolonged in seedling trays, however, the plants become increasingly constrained by both the aerial and the below-ground environment, and growth rate decreases; if plants are kept in seedling containers past the time in which they are making active growth, growth after transplanting and yield may suffer. This growth decrease is particularly noticeable in the smaller cell sizes, and may not be alleviated by transplanting into non-limiting growing environments. Our results are not in agreement with these previous reports; Fig. 2 showed that there was an *Impatiens wallerana* dry weight increase at the sales stage when transplant was delayed two weeks, although when 512 plug cell was used. Both dry weight and main root length decrease would be more related to plug cell size and paclobutrazol sprayed during nursery production than to transplant date at least by two weeks later the 'optimum transplant date'.

In summary, the productivity of cultivated plants is constrained by the relative plasticity of the response to environmental and technological stresses. The understanding of the response of ornamental bedding plants to particular short- and long-term stresses is limited even further by interactions with other stresses in the crop such as the 'root restriction' imposed by small plug cell tray and/or growth regulators which inhibit plant growth. Since plants crowded together above ground are generally also limited in below-ground space, there may not be a single factor constraining growth in such situations. Since the cost of small transplants is lower than that of large, their advantage would be lower establishment costs. Our results showed that a potential problem exist, however, with small transplants, overriding these economic aspects and affecting their suitability.

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Addresses of authors: A. Di Benedetto and R. Klasman, Cátedra de Floricultura, Facultad de Agronomía, Universidad de Buenos Aires, Av. San Martín, 4453 (1417), Buenos Aires, Argentina, e-mail: dibenede@agro.uba.ar.