

Auxins Affect Posttransplant Shoot and Root Growth of Vinca Seedlings

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Abstract. Transplanting often causes root damage, and rapid root growth following transplanting may help to minimize the effects of transplant shock. The objective of this study was to determine the effects of NAA and IAA on posttransplant growth of vinca (*Catharanthus roseus* L.). Bare-root seedlings were germinated in a peat-based growing mix and transplanted into diatomaceous earth 10 days after seeding. Immediately after transplanting, seedlings were drenched with several concentrations of IAA or NAA (62.5 mL/plant). Both auxins increased posttransplant root and shoot growth, but the response was dose-dependent. The maximum growth occurred at concentrations of 10 mg·L⁻¹ (IAA) or 0.1 mg·L⁻¹ (NAA). The growth-stimulating effect of these auxins decreased at higher rates and NAA was highly toxic at 100 mg·L⁻¹, killing most of the plants. Unlike the growth of bare-root seedlings, plug seedling growth was not stimulated by drenching with NAA solutions. These results show that auxins have the ability to stimulate posttransplant growth of vinca, but their effects may depend on the application method, rate, and timing, and transplanting method. Chemical names used: 1-naphthaleneacetic acid (NAA); 1-indole-3-acetic acid (IAA).

Transplanting often causes root damage, reducing the effective root area. This limits the ability of plants to absorb water and nutrients (Kramer, 1983). Transplant shock can cause water stress (Berkowitz and Rabin, 1988), decrease nutrient uptake (Bloom and Sukrapanna, 1990), and make plants more susceptible to disease (Moss and Main, 1989). Rapid initiation of new roots and elongation of existing roots into the surrounding soil could be helpful in minimizing the effects of transplant shock.

Auxins are widely used in tissue culture to enhance initiation of new root primordia and stimulate root elongation. Relatively high concentrations are needed for the initiation of new roots, while root elongation is stimulated by lower concentrations (Pierik, 1985). Auxins are also used to stimulate rooting of cuttings that are difficult to root by other methods (Selby et al., 1992); 3-indolebutyric acid (IBA) and NAA are the active ingredients in commercially available rooting hormones.

Exogenous auxin applications can inhibit root elongation (Eliasson et al., 1989; Pilet and Saugy, 1987), but this appears to depend on the amount of auxin applied. Auxins can stimulate root elongation and nutrient uptake when applied at an appropriate rate. Lippmann et al. (1995) and Leinhos and Bergmann (1995) studied the effects of auxin-producing bacte-

ria and exogenous auxin applications on the root and shoot growth of corn (*Zea mays* L.) and reported that auxins could stimulate root elongation and lateral root production. The effects of IAA applications on root growth were also reflected in the shoot growth of the plants (Lippmann et al., 1995). Exogenous IAA applications also increased Ca, K, Mg, P, Fe, and Zn concentrations in the roots (Leinhos and Bergmann, 1995). Blakely et al. (1988) increased lateral root production of radish (*Raphanus sativus* L.) with auxins.

Auxins are used in plant growth regulators developed to minimize transplant shock (e.g., Vitamin B-1 hormone concentrate; Amvac Chemical Corp., Newport Beach, Calif.; PGR IV; MicroFlo Co., Lakeland, Fla.). However, these formulations also contain other ingredients that may affect plant responses. Although auxins have potential benefits in plant production, their effects on growth and development of commercial bedding plants in vivo have not been studied in detail. The objective of this study was to quantify the effect of different rates of auxins on the shoot and root growth of vinca. Vinca was chosen as a model species because it establishes slowly and has been problematic for many growers throughout the southeastern United States. Growers have reported problems associated with poor posttransplant growth and small root systems of vinca (Thomas and Wade, 1997).

Materials and Methods

Experiment 1. Bare-root seedlings in diatomaceous earth. Vinca 'Cooler Peppermint' seeds were planted in open flats filled with a peat-based growing mix (Redi-Earth; The Scotts Co., Marysville, Ohio) 24 Sept. 1996. They were germinated in the dark in a laboratory for 6 d at 21 °C. Seedlings were transferred to a double-layer polyethylene green-

house 8 d after seeding and transplanted into cell packs (32 cells/flat, 166 mL/cell) filled with diatomaceous earth (CG-2 Isolite; Sundine Enterprises, Arvada, Colo.) 10 d after seeding. The cotyledons had unfolded at this stage, but true leaves had not yet emerged. During transplanting, most of the growing mix was removed from the root system by dipping the roots in water. Diatomaceous earth was used as a posttransplant growing medium in this initial experiment because it is easy to remove from the root system and thus facilitates accurate root size measurements. Diatomaceous earth is a chemically inert material, consisting of SiO₂ (78%), Al₂O₃ (12%), and Fe₂O₃ (5%), with a low cation exchange capacity (<0.02 meq·g⁻¹).

The seedlings were treated with varying amounts of reagent grade IAA or NAA within 2 h after transplanting. The auxins were first dissolved in a small volume (<5 mL) of ethanol and then added to water. The IAA was applied at concentrations of 0.1, 1.0, 10, and 100 mg·L⁻¹, and NAA at 0.01, 0.1, 1, 10, and 100 mg·L⁻¹. Controls were treated with water. All treatments were applied to a group of 32 plants, using 62.5 mL/plant, by placing the cells in a watertight tray and adding the solution to the tray. The seedlings were left in the trays until all the solution, which did not come in contact with the shoots of the plants, had been absorbed by the diatomaceous earth.

Plants were fertilized twice weekly with 20N-4.4P-16.6K water-soluble fertilizer (20-10-20 Peat-Lite Special, The Scotts Co.), containing N at 200 mg·L⁻¹, starting 4 d after transplanting (DAT). During the experiment, Fe deficiency symptoms (interveinal chlorosis of the younger leaves) developed, probably because of high growing medium pH (7.2 at 38 DAT). Plants were drenched with 1 mmol·L⁻¹ chelated Fe (chelated liquid iron; Southern Agricultural Insecticides, Palmetto, Fla.) at 38 and 45 DAT, which relieved the deficiency symptoms. Temperature set points for the greenhouse were 23 (day) and 18 °C (night). Total daily photosynthetic photon flux (PPF) in the greenhouse averaged 13.5 mol·m⁻²·d⁻¹.

The experimental design was a randomized complete block with four replications and 16 plants per replication. Two plants were harvested from every experimental unit at ≈10-d intervals (14, 24, 34, 45, 54, and 63 DAT). Root (DM_{root}) and shoot dry mass (DM_{shoot}) were determined separately. Because of a severe phytotoxic response of the plants to an auxin application of 100 mg·L⁻¹, these data were not used for the analysis. Data were analyzed by multiple regression analysis using a third-order polynomial equation:

$$\ln(\text{DM}) = a_0 + a_1 \cdot \text{DAT} + a_2 \cdot C + a_3 \cdot \text{DAT} \cdot C + a_4 \cdot \text{DAT}^2 + a_5 \cdot C^2 + a_6 \cdot \text{DAT} \cdot C^2 + a_7 \cdot \text{DAT}^2 \cdot C + a_8 \cdot \text{DAT}^3 + a_9 \cdot \text{DAT}^2 \cdot C^2 + a_{10} \cdot C^3,$$

where:

DM = shoot or root dry mass (mg/plant)

a₀, ..., a₁₀ = regression parameters,

C = log(concentration + 0.001) for NAA models, and log(concentration + 0.01) for IAA models.

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Nonsignificant terms ($P > 0.05$) were removed from the model using backward elimination. When higher order terms were significant, lower order terms of that same variable were kept in the model, even if they were nonsignificant. The resulting models were used to calculate the relative growth rate (RGR) of both the roots and the shoots (RGR_{root} , RGR_{shoot}) as the first derivative of $\ln(\text{DM})$ with respect to DAT (Hunt, 1982):

$$\text{RGR} = d[\ln(\text{DM})]/dt = a_1 + a_3 \cdot C + a_4 \cdot 2 \cdot \text{DAT} + a_6 \cdot C^2 + a_7 \cdot 2 \cdot \text{DAT} \cdot C + a_8 \cdot 2 \cdot \text{DAT} \cdot C^2 + a_9 \cdot 3 \cdot \text{DAT}^2$$

Although RGR is normally calculated for shoots or whole plants, RGR_{root} (the production of new DM_{root} per unit existing DM_{root}) is a useful parameter for determining changes in root growth. Optimal auxin concentrations for the stimulation of RGR were determined from the first derivative of the functions describing RGR, with respect to C.

Experiment 2. Plug seedlings in a peat-based medium. A second study was conducted to mimic commercial growing practices. Vinca 'Cooler Peppermint' was seeded in plug flats (288 cells/flat, 7.3 mL/cell) filled with a peat-based germination mix (Redi-Earth, The Scotts Co.) on 16 Jan. 1997. Seeds were germinated in the dark at 22 °C and transferred to a greenhouse 11 d after seeding. On 6 Mar., when the seedlings had reached developmental stage 4 (Styer and Koranski, 1997), they were transplanted into cells (32 cells/flat, 166 mL/cell) filled with a peat-based growing mix (MetroMix 300, The Scotts Co.). Auxin solutions were applied as a drench over the top of the plants, immediately after transplanting, at a rate of 1 L/flat (31 mL/cell). Solutions contained NAA at a concentration of 0, 0.1, 1, 10 or 100 $\text{mg} \cdot \text{L}^{-1}$. Growing conditions were as described for the first experiment, with an average daily PPF of 15 $\text{mol} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$.

Four plants were harvested from every experimental unit at weekly intervals, until 49 DAT. The roots were washed in water to remove the growing medium, and shoot and root dry mass were determined after drying the plants in a forced air oven at 70 °C for a minimum of 3 d. The experimental design was a randomized complete block with four replications and a group of 32 plants per replication. Data were analyzed as described in the first experiment, except that the NAA concentration was transformed according to $\log(\text{Conc}_{\text{NAA}} + 0.01)$ and data from the 100 $\text{mg} \cdot \text{L}^{-1}$ treatment were not used in the regression analysis because of severe toxicity.

Results and Discussion

Experiment 1. Bare-root seedlings in diatomaceous earth. The response of vinca root and shoot growth to exogenous auxin applications was highly dose-dependent (Figs. 1 and 2). Both IAA and NAA had the ability to stimulate root and shoot growth. Auxin effects were visually detectable at 34 DAT, and became more obvious as the experiment progressed. Maximum growth stimulation occurred at 10 $\text{mg} \cdot \text{L}^{-1}$ IAA (Fig. 1) and 0.1 $\text{mg} \cdot \text{L}^{-1}$ NAA (Fig. 2). At higher concentrations, response

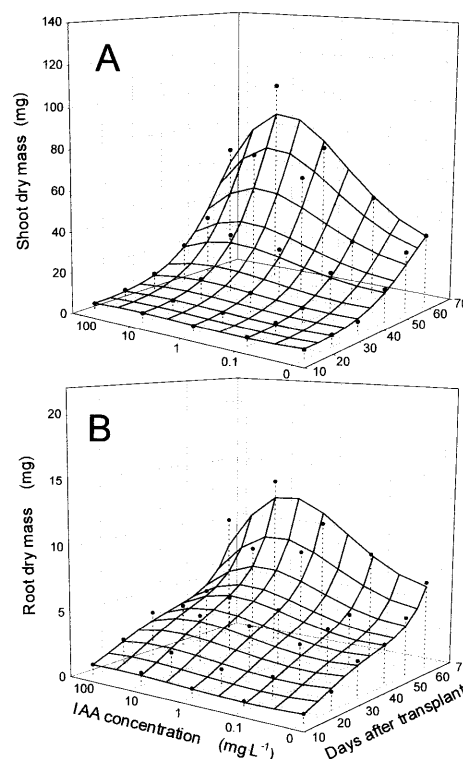


Fig. 1. The effect of IAA on shoot (A) and root dry mass (B) of vinca grown in diatomaceous earth (Expt. 1). Seedlings were treated with 62.5 mL of several concentrations of IAA at transplanting (10 d after seeding). Data points are indicated by ●, while the solid lines indicate the model $[\ln(\text{DM}_{\text{shoot}})] = -1.9793 - 0.0901 \cdot \text{DAT} + 0.003895 \cdot \text{DAT}^2 - 2.97 \cdot 10^{-5} \cdot \text{DAT}^3 + 0.08781 \cdot C + 0.06724 \cdot C^2 - 0.0473 \cdot C^3 + 0.003716 \cdot \text{DAT} \cdot C - 0.003168 \cdot \text{DAT} \cdot C^2$, $r^2 = 0.89$; $[\ln(\text{DM}_{\text{root}})] = -3.1874 + 0.2616 \cdot \text{DAT} - 0.005462 \cdot \text{DAT}^2 + 4.326 \cdot 10^{-5} \cdot \text{DAT}^3 + 0.2425 \cdot C + 0.07628 \cdot C^2 - 0.05144 \cdot C^3 - 0.003122 \cdot \text{DAT} \cdot C^2$, $r^2 = 0.82$; $C = \log(\text{Conc}_{\text{IAA}} + 0.01)$.

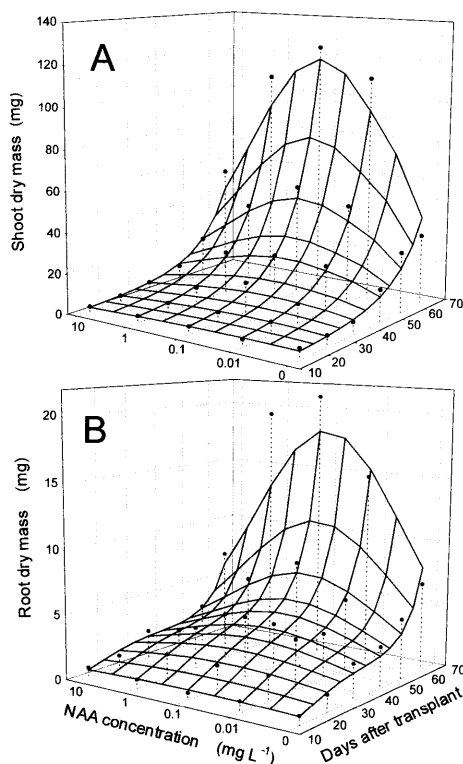


Fig. 2. The effect of NAA on shoot (A) and root dry mass (B) of vinca grown in diatomaceous earth (Expt. 1). Seedlings were treated with 62.5 mL of several concentrations of NAA at transplanting (10 d after seeding). Data points are indicated by ●, while the solid lines indicate the model $[\ln(\text{DM}_{\text{shoot}})] = 0.7814 + 0.01596 \cdot \text{DAT} + 0.000691 \cdot \text{DAT}^2 - 0.1956 \cdot C - 0.004778 \cdot \text{DAT} \cdot C - 0.003945 \cdot \text{DAT} \cdot C^2$, $r^2 = 0.91$; $[\ln(\text{DM}_{\text{root}})] = -3.896 + 0.3433 \cdot \text{DAT} - 0.008267 \cdot \text{DAT}^2 + 7.073 \cdot 10^{-5} \cdot \text{DAT}^3 - 0.0542 \cdot C - 0.00731 \cdot \text{DAT} \cdot C - 0.003648 \cdot \text{DAT} \cdot C^2$, $r^2 = 0.84$; $C = \log(\text{Conc}_{\text{NAA}} + 0.001)$.

decreased and plants treated with NAA at 10 mg·L⁻¹ were comparable in size to untreated controls. The highest NAA rate (100 mg·L⁻¹) was highly phytotoxic. The roots of these plants turned brown, were necrotic at 34 DAT, and most of the plants eventually died. Similar, but less severe, symptoms were seen when NAA was applied at 10 mg·L⁻¹. Higher concentrations of IAA (>1 g·L⁻¹) would probably have had the same detrimental effects, since the overall response of the plants to IAA and NAA was similar, except that NAA was ≈15 to 100 times more active than IAA. However, the highest IAA rate in this study (100 mg·L⁻¹) was not high enough to adversely affect plant growth.

The difference in optimal concentration is not surprising, since NAA is a synthetic auxin, which has much higher activity in most biological processes than IAA. For example, Blakely et al. (1988) found that NAA was 30 times more active than IAA in stimulating lateral root formation in radish seedling roots, while indolebutyric acid was 6 times less active than IAA.

Shoot growth was very slow during the first 30 DAT, while root growth was relatively rapid following transplanting. This resulted in large changes in the shoot : root ratio of the plants during the experiment (Fig. 3), but there were no significant differences in shoot : root ratios among the treatments (not shown). Thus, whether the auxin applications increased shoot growth indirectly by stimulating root growth, or had a similar direct effect on both root and shoot growth, is impossible to determine.

These differences in root and shoot growth are clearly reflected in the RGR of the roots and the shoots (Figs. 4 and 5). Both in the IAA and NAA treatments, RGR_{root} was relatively high (0.12–0.16 g·g⁻¹·d⁻¹) at 15 DAT and decreased to 0.013–0.026 g·g⁻¹·d⁻¹ at 39 DAT, after which it increased again. The increase in RGR_{root} after 39 DAT was more rapid in the NAA than in the IAA treatments. This resulted in a higher root dry mass and RGR_{root} in the NAA than in the IAA treatments at the end of the experiment. Because of the slow shoot growth, RGR_{shoot} was low shortly after transplanting, but increased rapidly during the experiment. In the IAA treatments, RGR_{shoot} reached a maximum (0.06–0.08 g·g⁻¹·d⁻¹) at 45 DAT, after which it declined again. In the NAA treatments, RGR_{shoot} increased throughout the entire experiment (Fig. 5), reaching values from 0.09 to 0.11 g·g⁻¹·d⁻¹ at 63 DAT.

Although differences in plant size among the treatments were not visible until 34 DAT, the regression results suggest that there was an effect of the auxin applications shortly after transplanting. The relative growth rates of both roots and shoots were affected by both auxins throughout the entire experiment (Figs. 4 and 5). The models for RGR_{root} predict an optimal stimulation of root growth at a concentration of 1 mg·L⁻¹ IAA and 0.01 mg·L⁻¹ NAA, whereas predicted optimal auxin concentrations for stimulation of RGR_{shoot} are 3.86 and 0.24 mg·L⁻¹ for IAA and NAA, respectively.

Experiment 2. Plug seedlings in a peat-

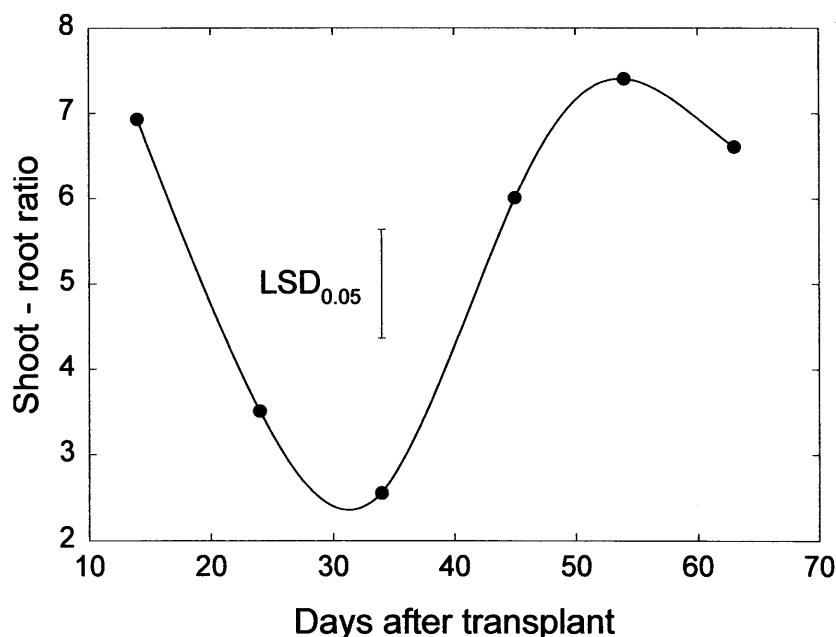


Fig. 3. Shoot : root ratio during the development of vinca seedlings. Shoot : root ratio was not affected by exogenous auxin applications and data were averaged over treatments. Bare-root seedlings were transplanted into diatomaceous earth at 10 d after seeding (Expt. 1).

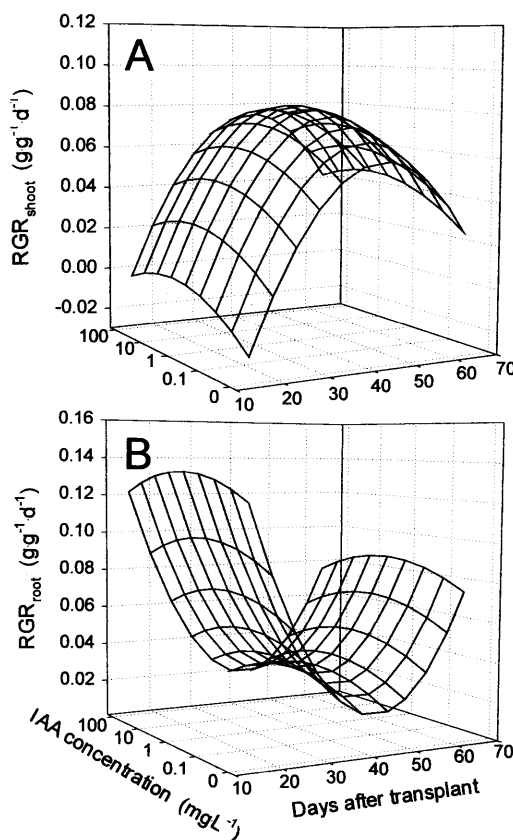


Fig. 4. The effect of IAA on the relative growth rate of the shoots (A) and roots (B) of vinca grown in diatomaceous earth (Expt. 1). Relative growth rate was calculated as the first derivative, with respect to days after transplanting (DAT), of a third-order polynomial model fitted to the natural logarithm of the dry mass data. $RGR_{\text{shoot}} = -0.0901 + 7.79 \cdot 10^{-3} \cdot \text{DAT} - 8.91 \cdot 10^{-5} \cdot \text{DAT}^2 + 3.72 \cdot 10^{-3} \cdot C - 3.17 \cdot 10^{-3} \cdot C^2$; $RGR_{\text{root}} = 0.2616 - 0.0109 \cdot \text{DAT} + 1.298 \cdot 10^{-4} \cdot \text{DAT}^2 - 3.12 \cdot 10^{-3} \cdot C^2$; $C = \log(\text{Conc}_{\text{IAA}} + 0.01)$.

based medium. Drenches with NAA solutions did not increase the growth of transplanted vinca plugs (Fig. 6). Both root and shoot growth were inhibited by NAA drenches containing 10 mg·L⁻¹, while NAA at 100 mg·L⁻¹

was phytotoxic and inhibited growth almost completely. At four DAT, plants treated with 100 mg·L⁻¹ showed leaf curling and the leaves were more erect than those in other treatments. These symptoms persisted throughout most of

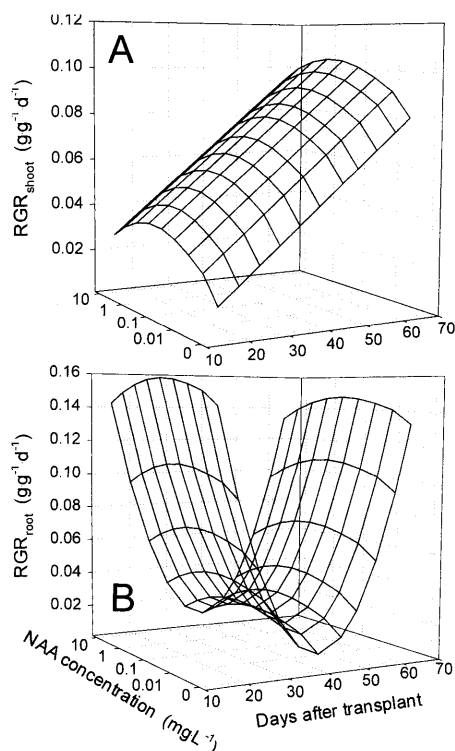


Fig. 5. The effect of NAA on the relative growth rate of the shoots (A) and roots (B) of vinca grown in diatomaceous earth (Expt. 1). Relative growth rate was calculated as the first derivative, with respect to days after transplanting (DAT), of a third-order polynomial model fitted to the natural logarithm of the dry mass data. $RGR_{shoot} = 0.01596 + 1.38 \cdot 10^{-3} \cdot DAT - 4.78 \cdot 10^{-3} \cdot C - 3.95 \cdot 10^{-3} \cdot C^2$, $RGR_{root} = 0.343 - 0.01653 \cdot DAT + 2.122 \cdot 10^{-4} \cdot DAT^2 - 7.31 \cdot 10^{-3} \cdot C - 3.65 \cdot 10^{-3} \cdot C^2$; $C = \log(\text{Conc}_{NAA} + 0.001)$.

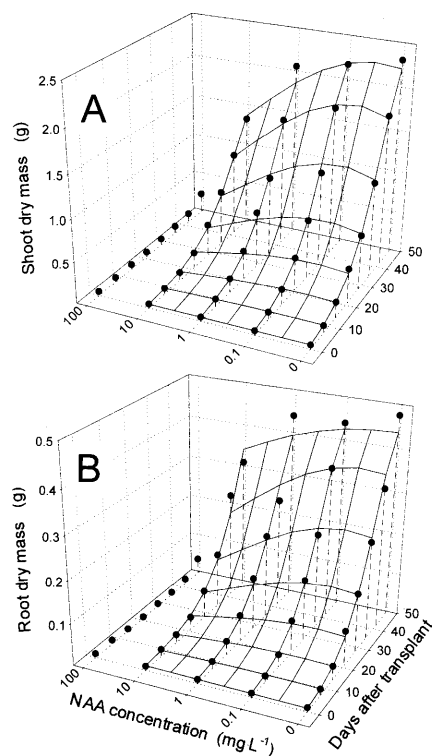


Fig. 6. The effect of NAA on the shoot (A) and root (B) dry mass of vinca. Plug seedlings were transplanted into a peat-based growing medium and drenched with several concentrations of NAA (Expt. 2). Data points are indicated by ●, while the solid lines indicate the model [$\ln(DM_{shoot}) = 3.873 + 0.0785 \cdot DAT + 0.001027 \cdot DAT^2 - 0.000022493 \cdot DAT^3 - 0.0325 \cdot C - 0.0223 \cdot DAT \cdot C - 0.01021 \cdot DAT \cdot C^2 + 0.000371 \cdot DAT^2 \cdot C + 0.000177 \cdot DAT^2 \cdot C^2$, $r^2 = 0.98$; $\ln(DM_{root}) = 2.323 + 0.0607 \cdot DAT + 0.001585 \cdot DAT^2 - 0.0000265 \cdot DAT^3 + 0.1126 \cdot C - 0.03648 \cdot DAT \cdot C - 0.010723 \cdot DAT \cdot C^2 + 0.00065 \cdot DAT^2 \cdot C + 0.000206 \cdot DAT^2 \cdot C^2$, $r^2 = 0.97$; $C = \log(\text{Conc}_{NAA} + 0.01)$].

the experiment and the plants remained small. Applications of NAA at 0.1 or 1 mg·L⁻¹ had a negligible effect on growth of the plants.

The differences in response to exogenous auxin applications between the bare-root and plug seedlings may have been caused by several factors. Developmental stage of the plants at the time of treatment may be important, since hormonal action is greatly dependent on the sensitivity of the plant to that hormone (Trewavas, 1982, 1983). Pilet and Saugy (1987) found that the effect of IAA treatment on root growth depends on the initial elongation rate. Growth of fast-growing roots was stimulated by exogenous applications of low concentrations of auxins, while that of slow-growing roots was inhibited. Based on the changes in RGR_{root} (Figs. 4 and 5) during the development of the bare-root seedlings, auxin would be expected to be more effective in young seedlings than in 49-day-old plugs, because of the decrease in RGR_{root} during early development. Application method may be another contributing factor to the different responses. Shoots of the bare-root transplants did not come in contact with the auxins, while the foliage of the plugs was wetted during the applications of the NAA solutions. Finally, transplanting method may be important. Significant root damage is more likely to occur during transplanting of tender, young bare-root seedlings than during transplanting of older plug seedlings.

Absorption of the NAA by the growing medium does not appear to have been an important factor, although many organic compounds can be bound to organic matter (Briggs, 1981). Toxicity occurred both in bare-root transplants and plugs, when NAA was applied at 100 mg·L⁻¹, suggesting that NAA was not bound by the peat-based growing mix. If significant absorption of NAA to the organic matter had occurred, the NAA dose : response curve for the plug seedlings would have shifted to higher NAA concentrations, but this was not the case.

Conclusions

Auxins (IAA and NAA) increased the posttransplant growth of young bare-root vinca seedlings. Maximum growth stimulation of both roots and shoots was obtained with IAA at 10 mg·L⁻¹ and NAA at 0.1 mg·L⁻¹. Auxin applications did not alter the shoot : root ratio of the plants. Posttransplant growth of plug seedlings was not increased by NAA drenches to the shoots and roots of the plants. This study suggests that auxins may be useful in stimulating posttransplant growth, but the sensitivity of vinca to exogenous auxin applications may depend on the transplant method, growing medium, application method, or developmental stage of the plants. Although auxins have the potential to greatly improve vinca establishment and increase plant growth, the conditions under which they are effective have yet to be determined. Further research addressing possible interactions among application method, rate, and timing is needed to determine how auxins can be used in commercial

production schedules. Because of their capacity to greatly stimulate growth, auxins may become a valuable tool for bedding plant producers.

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